SOIL EROSION—ITS PREVENTION AND CONTROL

GOVERNMENT OF MADRAS

SOIL EROSION

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PREFACE

THE CONTROL and prevention of soil erosion is a subject of great national importance. The Government of Madras therefore decided that a text-book on soil erosion should be prepared for the use of departmental officers and for teaching the subject in the Agricultural and Forest Colleges. They appointed a committee consisting of the Heads of the Departments of Irrigation, Agriculture, Forest and Public Health to form an Editorial Committee presided over by a Chief Editor to bring out such a text-book. The present volume has been compiled by that Committee. It is hoped that this compilation will be of practical use to departmental officers and all others who are concerned with the prevention and control of soil erosion.

Several photographs illustrating the types of soil erosion included in the volume were specially taken on the ground and others have been taken from other publications duly acknowledged in the appropriate places. By the courtesy of the Pudukkottai Durbar, ten photographs of erosion in that State have also been included.

Any material errors found in the compilation or suggestions for improvement may be communicated to the Secretary to the Government of Madras, Development Department, Fort St. George.

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(Retired Chief Engineer for Irrigation, Government of Madras),
Chief Editor.

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SOIL EROSION—ITS PREVENTION AND CONTROL

CHAPTER I

INTRODUCTION

"SOIL" is the product of the action of weather on the solid crust of the earth. "Weathering" is the term applied to the natural process which produces the widespread decay on the surface of the earth. Of the natural processes, the four that deserve special consideration are—

(1) Changes of temperature; (2) saturation and desiccation; (3) frost; and (4) rain.

Temperature.—Where days are excessively hot with temperature over 110° to 130° F. under a tropical sun and the nights are comparatively cool with temperature of 65° to 70° F. as in the Ceded districts of the Madras Province, considerable expansion by day and contraction by night takes place imposing heavy strains on the earth's crust which splits up, gradually peels off and is reduced to smaller fragments and finally to dust.

Saturation and desiccation.—Another cause of the decay is to be sought in the alternate soaking of the exposed surfaces of rock in rain and their drying in sunshine whereby the compact particles of the stone are loosened and fall to powder.

Frost.—The weathering action is greatly accentuated in very cold regions on account of freezing of the water that has percolated into the crevices. Water expands on freezing and the stresses set up are enormous and cause splitting up of the earth's solid crust.

Rain.—In falling through the atmosphere, rain absorbs the gases of the air and with their aid, attacks the surface of the rock. With the oxygen in solution, it further oxidizes the parts which are partially oxidized already and destroys the cohesion. With the aid of carbon dioxide, it dissolves some of the more soluble constituents and forms carbonates.

When the ground is protected with vegetation, decay is retarded; but in the absence of vegetation, the outer crust of the decayed layer is apt to be washed off by rain; or when dried to powder may be taken away and scattered by wind.

Typical soil profile in sandstone and granite are shown in Figs. 1, 2, 3 and 4. In Fig. 1, the gradual passing from the solid sandstone to the broken up sandstone, and thence to the earthy layer that supports the vegetation of the surface is clearly shown. Traced from below upwards, the rocks become more and more broken and crumbling, with an increasing number of rootlets that strike freely into it in all directions, until it passes finally into the uppermost dark layer of vegetation soil or humus. Similarly, in Fig. 2, the granite passes from hard, compact, crystalline rock that may be quarried in large solid blocks, into innumerable fragments which are still lying in the original position, then into rounded boulders, and so on until you reach the layer of mere sand or sandy clay in which a few hard kernels are still left, and into the soft layer roots may descend from the surface. Like the sandstone, the granite merges above into the overlying soil. We thus have three distinct layers made up of the rock, the soil and the sub-soil. In the soil plants grow and die; worms, insects and larger animals live and die on the surface. All these add their mouldering remains to the soil and supply organic matter on which the fertility of the soil so much depends. It is this soil that we need to save and conserve for the survival of humanity.

There is, however, one limitation to it. Natural weathering creates the soil; and when soil is altogether prevented from washing away, further weathering stops or is rendered so slow that it ceases to add to human wealth. A certain amount of controlled erosion is therefore a desideratum. Thus, the rich alluvial deltas of the Nile, the Ganges, the Mahanadi, the Cauvery, the Kistna and the Godavari would not have been possible without it.

Under natural conditions the disintegration of rock and subsequent formation of soil proceed at approximately the same pace as soil denudation, and under normal conditions of geological erosion a balance is struck between the two processes. Where this balance is destroyed, accelerated erosion sets in.

In an age when the development of industry is accepted as the index of progress, it is often forgotten that the fundamental industries without which the human race could not exist are the culture of the soil and the exploitation of the natural resources that lie below it. Fundamental to life itself is the fertility of the soil on which its productive capacity depends. It can be realized without further

discussion, therefore, that soil erosion which gradually wears away the soil is a destructive process to be regarded with the gravest misgivings. That it has received the little attention history shows is most remarkable. Especially has this been the case in countries where agriculture has expanded rapidly. Cases which can be cited are America, Africa, India and Australia.

Lessons from the past.—Erosion is not a process that has developed in modern times. It has gone on from pre-historic times since man first turned the topsoil in order to grow food. The history of erosion and its influence on the various civilizations which have risen and fallen is in itself a most interesting study. It is impossible in a relatively short treatise to go into detail and for this reason only the briefest precis can be given. It is, however, impossible to ignore it.

Here a quotation from the introduction to the *Arabian Nights* is worth repetition: "The lives of former generations are a lesson to posterity that a man may review the remarkable events which have happened to others, and be admonished, and may consider the histories of people of preceding ages and all that hath fallen them and be restrained."

Archæological research of the last century has established the high degree of civilization reached by the ancients judged by their ability in constructing buildings and irrigation works, and in making furniture, ornaments, etc. On such evidence we must accept the prosperity of those nations of the past. Yet, what do we find of them at the present time? Mesopotamia, a land well developed in the time of the Babylonians, Assyrians, Chaldeans and Persians is now virtually a desert, a land of drifting sand. Palestine and Syria together with the southern shores of Turkey, the home of the Phœnicians, can no longer be considered prosperous. Whereas this nation had a relatively highly developed agriculture with irrigated terraces in olden times, it has today a very primitive type of agriculture confined to small areas. The Greeks who learnt their agriculture largely from the Phœnicians left records of their methods. Writers, such as Xenophon, Homer and Hesiod have left history which is similar to that of the Phœnicians. Today Greece is a country of bare hills with agriculture confined to relatively small areas. The same story is repeated by the Romans and the Carthagenians.

In all these histories the process of deterioration is very similar. Agriculture developed on the very fertile silts brought down by the rivers from the hills and deposited in the plains. The hills were for the most part covered by thick forests, good examples being the ranges of Lebanon, Taurus and the Appenines. As cities sprang up demands for timber and fuel from the hills arose. The demands of

concentrated populations for food led to the extension of agriculture which gradually encroached on the hills. In addition, the many wars which took place assisted in the denudation of the hills for military requirements. The result was the destruction of the forests and the exposure of the soil to the elements. With the rains the soil from the hills was washed away to the plains and to the sea. Cities once known to be seaports are now well inland. An instance may be quoted in the excavation of nearly 30 feet to reveal ancient Tarsus, known to have been visited by the fleet of Cleopatra, ten miles from the sea.

From the Mediterranean let us turn to India. The Aryans who invaded India about 2000 B.C. were an agricultural and pastoral people. So far as can be judged from the meagre evidence available, they cleared and burnt large areas of dense forests. The *Mahabharata* mentions the existence of large areas of dark and gloomy forests and gives the story of the burning of the great Khandava forest. The *Ramayana* also mentions heavy forests. Alexander the Great who invaded India about 300 B.C. tells through his recorder Arrian of the thick forests along the banks of the Jhelum which could conceal his armies. He also relates that the forests extended over a boundless tract of country and that the climate was salubrious as the dense shade mitigated the severity of the heat and copious springs supplied the land with an abundance of water. From this time until the Mohammedan conquest, forests continued to exist over considerable areas, the valleys and lands near the larger rivers being intensively cultivated. Gradually the migration of the Central Aryans with their flocks had its effect, and the forests were burnt to make room for agriculture. With the later invaders, however, came a period of destruction, the forests being regarded as a free gift of nature available to all. The general result was an increasing aridity consequent on the drying up of springs and the reduction of water available in the larger rivers. The remains of deserted cities can still be found in India in desert tracts showing that at one time the same areas carried a dense population. The change has been very slow, but it is impossible to deny that there has been a change.

Lessons from modern times.—The more spectacular pictures of soil erosion, however, come from more modern times, and it is these that have focussed public attention to the need for soil conservation. Two interesting cases come from France. The French Revolution of 1789 A.D. resulted in making the royal forests and game preserves free of access to the people. By 1803 it was necessary to limit the use of the forests because of floods as a result of forest denudation. By 1840 it was necessary to adopt a public policy of flood control. The great flood of 1856 in the Rhone valley was one

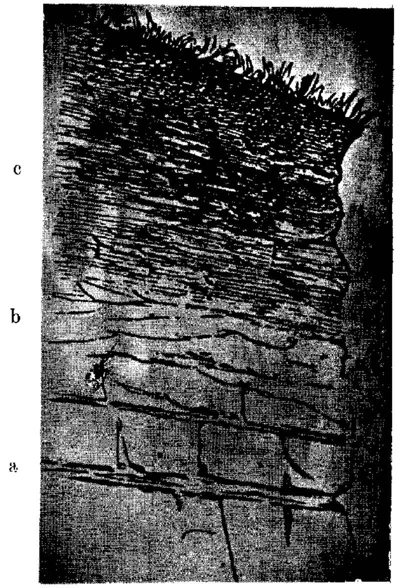

Fig. 1—PASSAGE OF SANDSTONE UPWARDS INTO SOIL

a — Solid sandstono. b — Broken up sand-stone. c — Earthy layer

(Taken from *Class Book of Geology* by *Geiten*)

Fig. 2—PASSAGE OF GRANITE UPWARDS INTO SOIL

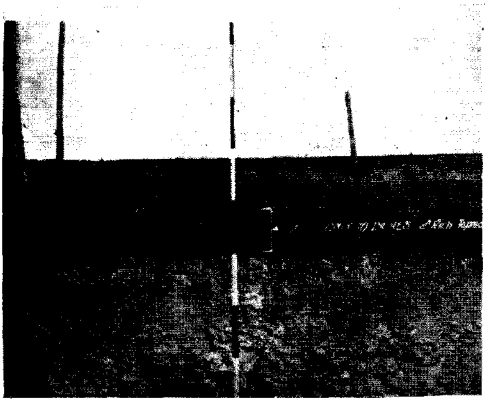

Fig. 3—TWO STAGES IN THE EROSION OF THE SOIL

First stage.—Note the poor structure of the half eroded compound with that of uneroded soil and the increasing poverty of the vegetation as erosion progresses

(Taken from *The Rape of the Earth* by *G. V. Jacks* and *R. O. Whyte*)

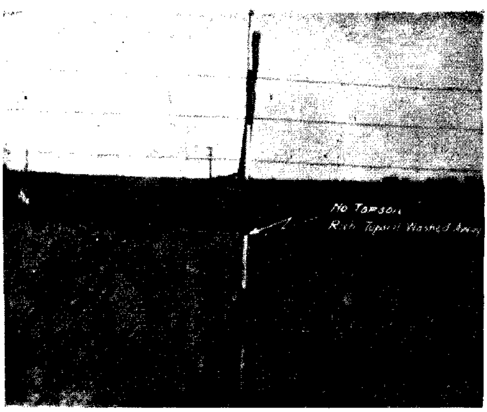

Fig. 4—*Second stage.*—The entire top soil has been washed away

(Taken from *The Rape of the Earth* by *G. V. Jacks* and *R. O. Whyte*)

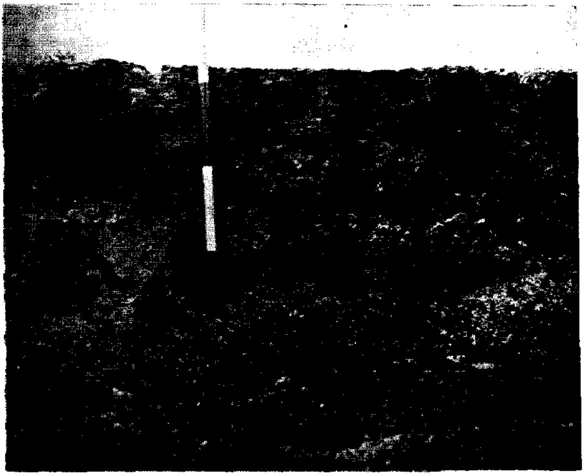

Fig. 5—Soil profile exposed by passing *vankas* or *nullas*

Fig. 6—Different horizons of soil profile exposed due to erosion

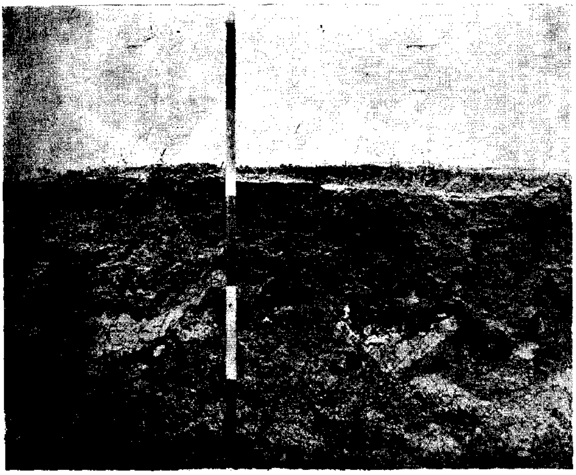

Fig. 7—THREE FEET OF SOIL PROFILE EXPOSED BY EROSION

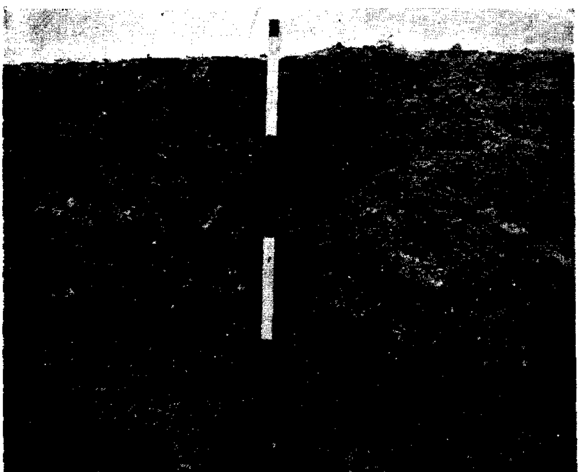

Fig. 8—FOUR FEET OF SOIL PROFILE EXPOSED BY EROSION

of the main reasons why the French Forestry Laws of 1860 and 1864 were passed leading to the revegetation of the mountain sides with either forest or grass. The success of these measures, costly though they have been, has led to their being copied by other European nations.

Along the shores of the Bay of Biscay the original vegetation was destroyed during political troubles in the middle ages. As a result, deposits of sea sand along the coast were carried inwards by wind and engulfed large areas of cultivated land. In addition, the sand drifts or dunes interrupted the flow of water courses to the sea and gave rise to desolate, malarial swamps. Reclamation work became inevitable on account of the public outcry. From 1788 A.D. up to the present day it has continued with complete success. Sand drift has been completely checked by gradual revegetation with grass followed by pine trees which are now being exploited systematically with profit. The area affected is well over 300 square miles.

More recent is the case of the United States of America. The Pilgrim Fathers landed in America at the end of 1620 A.D. They found a land extremely rich in natural resources and expansion was extremely rapid. Again, forest lands were cleared and extensive grass lands (prairies) ploughed under. By 1930 the following record of erosion was revealed from a preliminary erosion survey:—

	SQUARE MILES.
1 Cultivated land ruined and irrecoverable ..	78,000 (over half the total area of Madras).
2 Cultivated land now submarginal for cultivation.	78,000
3 Cultivated land impoverished severely by loss of top soil.	156,000

This does not take into consideration the erosion that has taken place on lands not under cultivation, for example, the national forests, where overgrazing and fires have produced erosion over appreciable areas.

In Africa where the problem is no less serious, it is of recent origin according to *Dudley Stamp* (1938). It is assuming very serious proportions as a result of the intensive exploitation of the land for agricultural purposes. The native system of cultivation known as "bush fallowing", which is also called "shifting cultivation" is best suited to the country. In this system a period of cultivation is usually followed by a long period of fallow—seven to ten years—during which bushes and trees grow. These form a natural protection against erosion. It is only when the period of fallow is reduced and clean ploughing, clean weeding, extensive clearing and such other practices are introduced that erosion is excessive.

Erosion in India and Madras.—In India the most spectacular case of erosion is that of the Punjab Siwaliks, a range of hills fringing the Himalayas. Here owing to the excessive grazing of cattle the natural vegetation on the outer slopes has been gradually reduced. Having first destroyed the grass, the herdsmen resort to cutting the branches of trees for the leaves which furnish the only remaining fodder for their cattle. Such denudation has resulted in widespread destruction in the plains below. There is evidence to show that some decades ago these hills were well wooded, and were the origin of perennial streams, which were used for irrigation. Such streams had well defined banks and were for the most part clear. Today the destruction of the natural cover has exposed the soil to the heavy rains which wash it down the steep slopes and drain into the streams which no longer run between well defined banks, since they are scoured out by the muddy torrents from higher slopes. Finally, floods of liquid mud issue into the plains and as the velocity of the water decreases, silt and sand are deposited to form detrital cones. As these cones extend, they engulf cultivated land and render it useless. The figures of successive settlements in Hoshiarpur district, show that the area of the detrital cones locally called *Cho* beds has increased as below:—

Year.			ACS.	Year.			ACS.
1852	..	..	48,206	1897	..	..	94,326
1884	..	..	80,057				

The total destruction to date has been estimated by competent observers at 150,000 acres or over 230 square miles.

In 1900 the Government of the Punjab attempted to check the denudation by passing the *Chos Act* which effected the closure of eroded areas to grazing and allowed grass cutting in its place. This improved the growth of grass and re-established natural cover to some extent. In recent years officers of the forest department have taken over the supervision of the area and are effecting improvements by the introduction of sound principles of grazing management together with general erosion and torrent control measures. Otherwise this story of destruction would have been much worse.

In comparison with this, Madras has been fortunate. In the first place the Indian peninsula is a very old geological formation having existed as a land area since the palaeozoic era and the soils derived from the weathering of the granitic and gneissic bed rock are very stable. Secondly its development has been slower as the major invasions of India have taken place from the north. As a result, the denudation of the uplands has not progressed to the same extent. A sound policy of reservation has saved appreciable areas of hill

forest. Despite this, the destruction of the soil is proceeding and the march of the hills to the sea is in train as can be seen from the rivers of sand which flow eastwards to the Bay of Bengal. Over the Ceded districts the climate is increasing in aridity and we hear the cry of famine with increasing frequency. This area is in fact developing into our main problem zone. In 1856 Major-General Fisher recorded that the Ramandurg hills of Bellary were covered with good jungle, and that the springs rising in the hills were perennial, and fed the Navihalla which supplied the Daroji tank throughout the year. By 1879 the same officer found the jungle destroyed for the most part, the springs dry except during the monsoon, and the Navihalla dry from February onwards.

Owing to soil erosion the bed of the Hagari river draining the hills to the south of Bellary has become choked with sand. The heavy winds of the south-west monsoon lift the sand from the river bed annually and deposit it further east to form sand dunes which have overwhelmed appreciable areas of cultivated land. This area, therefore, is a miniature example of what may happen in years to come, if soil erosion is allowed to continue.

In Tinnevelly district, there are several examples of wind erosion of a different type. The winds of the South-West Monsoon are again responsible. Lifting the light soil from the cultivated lands skirting the eastern edge of the ghats, they carry it eastwards until they meet the sea breeze from the Bay of Bengal. Their velocity is reduced and they deposit the light sand to form sand hills known as *theris*. Here again cultivated lands have been engulfed over thousands of acres.

The worst example of erosion to be seen in the province, however, is in the Nilgiris. On the outer slopes of these hills the clearance of natural forests to form plantations has resulted in severe soil loss which can never be replaced. Nor does the destruction end there. In the vicinity of the three towns Ootacamund, Coonoor and Kotagiri, the opening up of the land for cultivation of potatoes has had a similar result. Large areas can be seen today where the topsoil has been washed away and fields have either to lie fallow or the cultivator has to cultivate the less fertile subsoil with the aid of artificial manures. The Coonoor and the Kallar rivers demonstrate this loss, for they bring muddy water with every fall of rain. The serious silting of the Kateri lake is entirely due to erosion in the catchment area of the Kateri stream where cultivation has been carried on for many years. On the Nilgiri outer slopes, erosion is extensive along the southern fringe overlooking the Bhavani river within the Nilgiris revenue district boundary. It is unfortunate that this area where soil erosion is heavy is not much in the public eye.

In addition to these specific examples, however, soil erosion is taking place annually on most of the dry cultivated lands. This is seen in the numerous muddy streams flowing after rains. This results in the gradual loss of soil fertility. Again lands that could otherwise be cultivated continuously have to be kept fallow for some years so as to enable them to recuperate, and this entails loss.

From the few examples cited from the multitude available, it can readily be seen that soil erosion is not merely a natural phenomenon. It is also man-made. His methods of exploiting natural resources have been defective in the past and they continue to be so resulting in soil erosion.

Soil erosion is receiving world-wide attention today. Although erosion has been going on for centuries it is only in recent years that the enormous losses caused by erosion have been recognized. The need for protective measures has become urgent. The United States of America is the foremost country in the world in the collection and dissemination of knowledge on soil erosion. A chain of Experimental Stations dealing exclusively with the problem of erosion in its varied aspects has been established and a large mass of data collected. The results are made available to the farmers through a series of scientific articles, pamphlets and other publications. Wide publicity is given to such results. Farmers are encouraged to form soil conservation districts, which practise on co-operative lines the various control measures advocated by the officers of the Soil Conservation Service, under their technical help and guidance. The Soil Conservation Service deals comprehensively with erosion from the point of view of agriculture, forestry, engineering, etc.

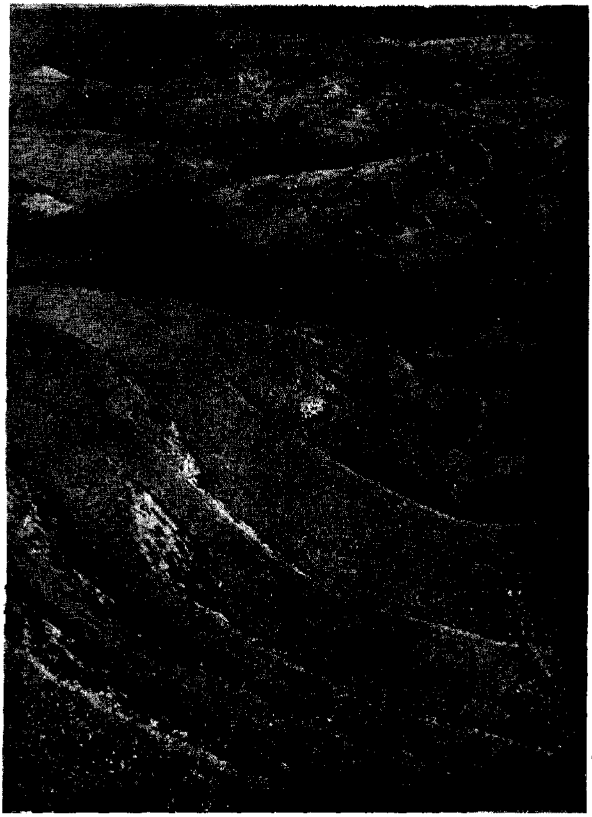

Fig. 9—WILDERNESS OF JUDAH—EXAMPLE OF SEVERE EROSION DUE TO DEFORESTATION AND NEGLECT

(Courtesy of the *Geographical Magazine* for June 1943)

Fig. 10—Bare hills from which rain and sand roar down like a tidal wave spreading devastation in the plains below

(Courtesy of the *Illustrated Weekly of India*, July 2, 1944)

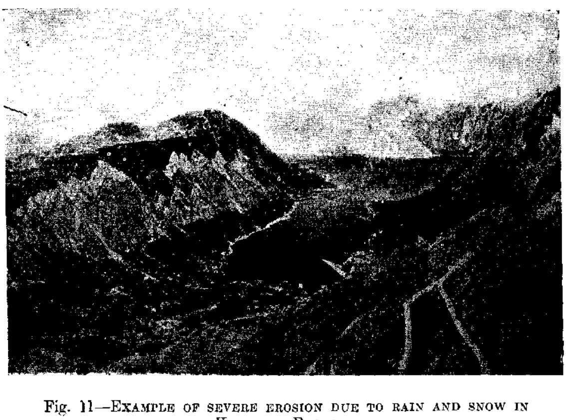

Fig. 11—Example of severe erosion due to rain and snow in Kotor in Bosnia

(Courtesy of the *Geographical Magazine* for January 1944)

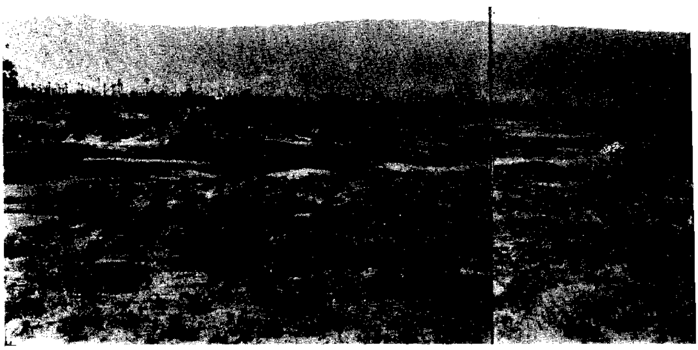

Fig. 12—Erosion in rear of the bungalows of the District Superintendent of Vizagapatam D

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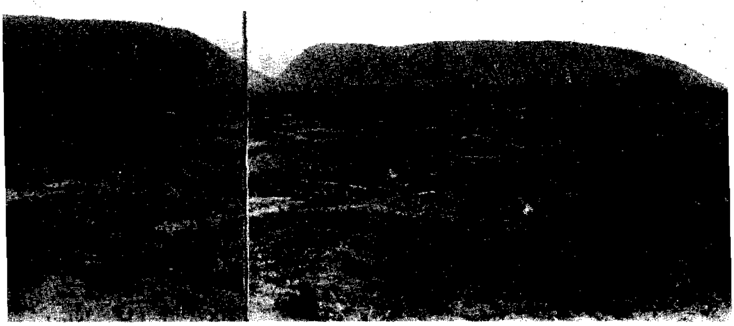


, THE DEPUTY INSPECTOR-GENERAL OF POLICE AND THE EXECUTIVE ENGINEER WALTAIR,
(RED LOAM)

Fig. 13 --Erosion near Scandal Point, Waltair (coastal erosion)

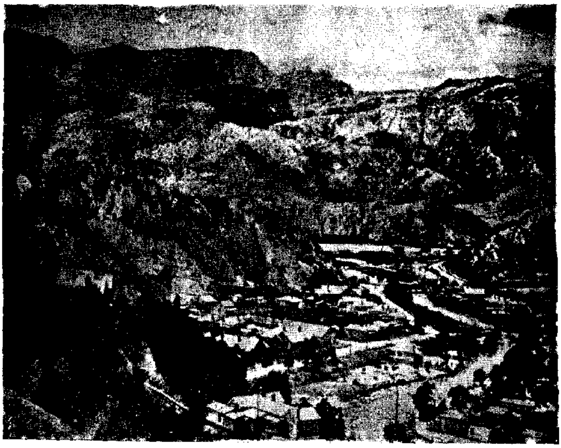


Fig. 14—QUEENSTOWN IN TASMANIA—CENTRE OF MINING INDUSTRY

The vegetation on the surrounding mountains was destroyed by sulphur fumes from the smelting of the ores

(Courtesy of the *Geographical Magazine* for January 1944)

Fig. 15—SHEET EROSION IN SOUTHERN NEW YORK

This erosion was the result of a heavy shower unofficially reported as 2 inches in 30 minutes. The slope from the left is 10 per cent. Deposition occurred where the slope flattened out

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 16—SHIFTING CULTIVATION ON STEEP SLOPE AT KADAMBUR IN COIMBATORE DISTRICT

Six inches top soil lost on the area, but still held up at the base of the tree

Fig. 17—DENUDATION ON WASTE LAND AT PEERKADAVU IN COIMBATORE DISTRICT

Ground cover completely denuded by overgrazing; trees lopped for thorns for fencing Sheet erosion serious

CHAPTER II

SOIL EROSION—CAUSES AND RESULTS

The soil.—A knowledge of certain facts fundamental to the problem of erosion is essential for a proper understanding of the subject. The soil is to be considered as " the uppermost weathered and disintegrated layer of the earth's crust " (*Bastall*, 1922). Its average depth in the world is estimated to be about 6 to 12 inches. Its depth is more in some places and less in others. This thin layer of soil resting on a rocky core is responsible for all plant growth. It supports all animal and human life. It is, therefore, our primary duty to protect this layer of soil and to see that its fertility is maintained.

Soil erosion.—Soil erosion is the loosening of the soil from the bed and the transportation of soil material from one place to another. This takes place through the action of wind or water in motion.

Geologic erosion.—Under natural undisturbed conditions an equilibrium will be established between the climate of a place (notably rainfall and temperature) and the cover of vegetation that protects the soil layer. Vegetation, trees and forests, retard the transportation of soil material and act as a check against excessive erosion. A certain amount of erosion, however, does take place even under this natural cover; but it is such a slow process that it is compensated for by the formation of soil under the natural weathering processes. Such erosion is called geologic erosion and proceeds in a natural undisturbed environment. It is not of much consequence so far as its effects on agricultural lands are concerned.

Accelerated erosion.—When vegetation is removed and land put under cultivation the natural balance existing between the soil, its vegetational cover and climate is disturbed. The removal of the surface soil takes place at a much faster rate than it can ever be built up by the soil forming processes. Erosion is thus accelerated. Erosion on cultivated lands is of this type.

Factors responsible for erosion.—Wind and water are the two agencies that cause erosion. There is much in common between

wind erosion and water erosion; the amount of soil material removed in either case depends on the velocity of the agency that causes the erosion; both affect the surface soil. The damage due to wind and water erosion, however, assumes different degrees of importance depending on the locality. Whenever soils without a cover of vegetation in a dry state are exposed to high winds we have wind erosion. The fine particles of the soil are lifted and carried to great distances. An extreme example of wind erosion will be found in figure 28. In South India as a whole wind erosion is not as extensive as water erosion. Light soils which are loamy and sandy are more susceptible to wind erosion than heavy soils. Along rivers like the Hagari and the Pennar in the Ceded districts, sand dunes are common. During summer when the river is dry, high South-West Monsoon winds lift up the sand and carry it along to great distances, depositing it on the black soils, and rendering the latter unfit for cultivation in the course of some years. If this drift is allowed to go on without hindrance, much of the cultivable land will get covered up annually Fixing up of the existing dunes and afforestation are measures for preventing the damage to cultivable land.

Erosion due to water.—Erosion due to water is the more serious and extensive type that occurs in many parts of the Madras Presidency, notably in the coastal districts, the black soil areas of the Ceded districts and in the hilly tracts of the Nilgiris. Two fundamental types of water erosion are " Sheet Erosion " and " Gullying."

Sheet erosion versus gullying.—In the case of sheet erosion movement of runoff water and eroded soil takes place in sheets, approximately the same amount of soil being removed from each place. When this moving mass assumes sufficient velocity it has a cutting action on the soil. If there is any depression at all in the field, a gully forms where the mixture of soil and water collects at a high speed. The runoff water carrying the surface soil flows down the gully with ever increasing velocity. If the velocity of the runoff water is doubled, its energy is increased four times and its cutting action on the soil is correspondingly increased; its capacity to carry in suspension soil material is increased 64 times. The gullies tend to deepen and widen with every rainfall. They cut up agricultural lands into small fragments and make them unfit for cultivation in course of time. Even where there are no depressions, the sheet flow usually tends to collect in rills which later develop into gullies. Of the two types of erosion, gullying is the more spectacular type while sheet erosion is the more dangerous and insidious type, creeping on unnoticed. The destructive action due to sheet erosion may not be felt in the first few years. Due to continuous erosion the productive

capacity of the land gets diminished consequent on the loss of fertility of the soil. Sheet erosion when neglected usually ends in gully erosion.

Other types of erosion—Stream erosion.—Erosion in valley streams, drainage courses and in large rivers in alluvial plains takes the form of bank cutting. The velocity of stream flow determines to a large extent the rate of erosion. Swift currents erode stream margins. Also bottom scour occurs when the bedfall of the stream is steep or when the discharge in the stream abruptly increases due to storm water received from its basin.

According to Sen Gupta, Public Works Department, Bengal: "Erosion is due to tortuous moment created by the difference in strength of the current of the adjoining particles of water. When due to an obstruction in the course of a river or otherwise, the slope is flattened, its effect in reducing the strength of the current is felt more nearer the bank than mid-stream, with the result that the change in the current from mid-stream to the bank is more rapid and the moment of tortion is increased. Therefore, when the surface fall is reduced bank erosion is increased increasing the tortuosity of the river." (*Central Board of Irrigation, India, Publication No.* 11, *page* 82.)

Floods confined between banks or margins cause more erosion than when the river, in full floods, spills and spreads over the adjoining lands. The stability of the materials underlying the top soil varies greatly in the course of a stream. Sandy and loose gravel beds are very unstable. Ordinarily heavy compact clays do not erode easily. Deep alluvial silts become unstable when saturated by prolonged inundation and cave readily even though the erosive action of the current is negligible. When the saturated alluvium releases the water in a falling flood, caving-in occurs. When the under-surface of a bank caves-in, the top soil, deprived of its support, slides and slips occur.

Erosion of river banks is a daily occurrence. It affects not only sand banks and shoals in the bed, but also the margins. It is particularly noticeable on the cusp or outer curvature at the beginning of bends in meandering streams. In flowing round bends cross currents develop that tend to eat away the outer bank and deposit the silt or sand bars on the inside curve. It may continue in one locality for many months and hundreds of acres of cultivable land including villages may be cut away and wholly disappear. It may be located at one point or other. When the curvature is so great that the eddies set up absorb all the energy, it ceases to cut abruptly and then it often happens that the stream abandons the channel and cuts a

straight course across the margin. When erosion is in progress the bank above water level becomes vertical. The bank below water level assumes a steep slope and as this slope is cut away by the current the bank above water level cracks, and then large pieces part away and fall into the river.

Erosion is practically absent when the river is at its lowest and it is said that it does not exist to a great extent when the river is full. But when this latter condition exists, the whole country is flooded and any erosion that occurs then is invisible.

High floods in the Godavari and the Kistna rivers beating directly on flood banks generally last only a few days and such rolling floods sweep over all obstruction in river bed such as sand shoals and *lankas*, in a fairly straight course and cause comparatively little harm to the river margins. But the low floods contained within the margins generally last long and are responsible for serious bank cuttings. Again the increased surface fall obtained in rising flood has a direct effect on the river bed which with its suddenness transports the bed sand to unsilted reaches of the river.

The power to scour and transport silt in flowing streams increases with velocity and decreases with depth of water (*Bellasis*, 1931). Velocity increases with depth in such a way that the actual scouring power may or may not increase with depth. In many of the rivers flowing in alluvial plains, scouring seems to be greatest at intermediate stages of the river. It is sometimes great in a falling flood because the soil in the bank is then soaked with water which in its process of draining out leaves large hollows.

Debris avalanche.—This form of erosion is common on steep hill slopes covered with dense vegetation and subject to heavy incidence of rainfall. On the Western Ghats where the annual rainfall is more than 200 inches, such earth movements take place during or just after heavy rains. On account of heavy incidence of rain the soil gets saturated with water and increases in weight. Also the soaked water relieves cohesion between soil particles and furnishes a sort of lubrication between them. Under these conditions the soil which otherwise would cling to a steep slope gradually begins to yield to gravitation. Sometimes these avalanches choke the waterways at the foot of the hill and cause floods in the valley.

Debris slides and caving.—This kind of erosion is sometimes responsible for widening of gullies. Steep gully margins in friable soils often cave-in during continuous and slow saturating rainfall. The side earth when once it is saturated with water increases in volume and small cracks develop, parallel to the gully wall. More water gets into the cracks and pushes out the vertical sides unless

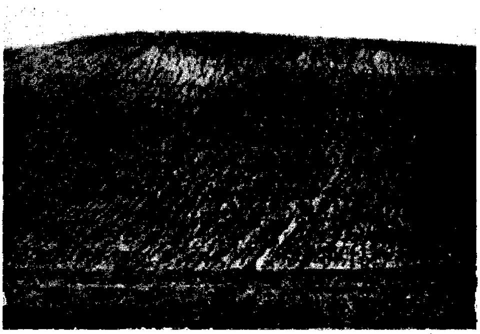


Fig. 18—Rill washing on summer fallow land in Washington

The thin sward of wheat for summer pasture in the foreground "stopped all visible erosion damage to the land"

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 19—Gullying in South Central New York

These gullies were formed during a two-day rain, July 7 and 8, 1935: The largest gully is as much as 12 feet deep in places. Water which was concentrated at the top of the ridge by beans and potatoes came through the woods and wrought havoc on the slope below

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 20—SLIP EROSION IN SOUTHERN NEW YORK

This soil had been stable since it was formed. Unusual conditions attending the heavy rains of July 7 and 8, 1935, brought about this situation. Approximately, 40,000 tons of soil material slid down the hill on the forenoon of the 8th following two days of heavy rains, leaving a hole 400 by 100 feet and covering 5 acres of beans on productive soil below. Slope of hill, 40 to 42 per cent

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 21—WATERFALL EROSION

Water concentrated in the depression which was a head land furrow 25 years ago is rapidly cutting its way back up the hill in this excellent pasture soil in Western Illinois

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 22—GULLY EROSION IN CENTRAL ILLINOIS

The soil is uneven lain with sand which is being continuously carried off by spring water. This form of erosion is difficult to control

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 23—CORN ROWS UP AND DOWN A SLOPE.

Much of the corn was washed out by the water concentrated in the planter tracks. Even the harrow-teeth marks led to gully formation

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

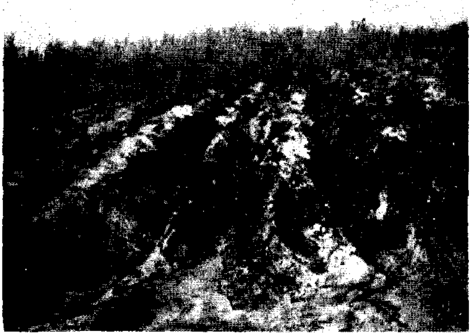


Fig. 24—FINAL RESULT OF UP-AND-DOWN HILL CORN PLANTING

This photograph taken in 1911 shows a field only a few years after the latest crop of corn was grown on it. The stalks still stood on some of the ridges

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

the side of the gully is protected by a sort of buttress formed by eroded debris in the gully.

Subsidence.—Gradual lowering of the earth's surface has often taken place in many areas due to mining operations. Subsidence in such cases causes local depressions which collect sufficient rainfall to submerge the crops. Sometimes in places where mining operations are carried on too close to the earth's surface, cracks and pot holes also develop during subsidence and much surface soil is washed into these hollows.

Erosion by waves.—Ocean and lake shore-lines are subject to cutting by waves accompanied by high winds dashing against them and scooping out the earth. The damaging action by waves is felt on earthen bunds of big reservoirs and tanks especially in localities where the tank bunds are located at right angles to the direction of heavy winds. In such localities unless the exposed portion of the bund is protected by stone revetment, the bund will get cut up by waves beating against the naked soil and may cause breaches in the bund.

In the sea, particularly, where it is shallow and breakers form, the advancing wave brings sand with it and deposits it, while the undertow withdraws a considerable part of this sand back into the sea. There are also the ocean currents along the coast produced by the rotation of the earth, climatic differences, phases of the moon, progression of tides, etc. Where these are powerful, they cause a rift of sand along the coast. The balance between these decide the erosions and accretions along a coast. Bars at the mouths of rivers where they enter the sea are caused by the combined effect of ocean currents, winds and river flows. Where the rivers are obstructed and only ebb and flow determine the coast line, erosion takes place.

Sea-coast erosions are scarcely taken note of, unless they are dangerous to harbours and important towns, because the cost of protecting any place from sea erosion is exorbitant and will be quite out of proportion to the value of land thus protected. A notable example of such coast protection on a large scale is the coast of Holland, bordering the North Sea, where a length of over 70 kilometers out of a total coast-line of 300 kilometers has been protected in one form or another.

Effects of soil erosion as is evident in rivers.—There is a great deal of literature which explains in general terms the effect of deforestation on rivers; but there is comparatively little, particularly relating to India, which provides direct evidence of increase in flood intensity, decrease in dry-weather flow and increase in silt burden (*Bellasis*, 1931.) Several authorities strike a note of warning by references to the disappearance of irrigation works on account of

deforestation. One glaring instance is the decay of irrigation system in Mesopotamia on account of neglect to control the catchment areas of the Tigris and the Euphratis rivers. Although there are differences of opinion as to whether forests do or do not affect rainfall, it is generally accepted that the destruction of undergrowth and grass has the immediate effect of increasing runoff thus exposing the surface soil to erosion.

When a drop of rain strikes on land covered with a thick blanket of vegetation it breaks into a spray of clear water which slowly finds its way into numberless channels that perforate the soil; but when the rain drop strikes the bare soil the forces of impact cause the fine soil particles to be taken into suspension and it becomes a drop of muddy water. As this drop of muddy water tries to sink into the soil, the fine particles of silt filter out and form a thin muddy film on the surface which chokes the pores of the soil. The result is that only a small portion of water can percolate into soil. The other part flows over the surface downhill into streams carrying with it a load of soil in the shape of eroded debris.

This is the story of one single drop of rain. Multiply that single drop several billion times and you get a flow of filmy, soil-charged water along the surface. As the volume of water increases, the velocity gets accelerated and the water acquires erosive power which is progressively increased. Soon, raging waters from torrential downpour tear away the surface soil from unprotected slopes, and pile it up in natural depressions of the land or gullies made by erosion. From these gullies and natural drainages water is discharged as from gutters into the little streams, which, when united, discharge the water with a high velocity into major streams with its potentialities for further damage.

Soil denudation has a cumulative effect on runoff. It results in quicker flow and earlier disposal of the flood water. Consequently, floods increase in intensity. There is, therefore, a greater tendency to scour. Coarse materials are carried away into rivers and such floods endanger flood embankments, irrigation head works, and their protective works, rail and road bridges, irrigation and navigation canals, storage reservoirs, hydro-electric projects and water-supply and pumping stations.

It has been proved in the United States of America from actual observation that floods in every section of the country have increased in frequency, volume and velocity in the course of the last 40 years. This is primarily attributed to accelerated runoff following removal of vegetative cover by overgrazing and deforestation.

Erosion debris is clogging many streams and shoaling channels of navigable rivers. The Kistna in its reaches between Ibrahimpatam

and Pondugalla and the Godavari in the neighbourhood of Chidipi and below Polavaram are examples. Erosion is also reducing the carrying capacities of drainage streams and is thus impairing the efficiency of irrigation systems. Heavy deposits of sand-silt in river beds in alluvial tracts have caused a rise in flood levels resulting in heavy damage to agricultural lands and industrial areas.

In America from actual surveys made in 1936 it has been found that the bed of the Rio Grande just above the head of Elephant Buttee Reservoir had risen by about 13 feet in the course of 22 years. Two miles further up the stream the bed had risen by about 7 feet. The natural results of such silting of the river are high flood levels which cause damage to surrounding country and swamping of valley lands. Dikes and other protective works constructed in river margins were overtopped and damaged by ever increasing floods. Considerable areas were sanded and extensive irrigated areas became permanent swamps. The high silt load in the flood waters of the Rio Grande is said to be due to the great load of silt sediment washing into that river from overgrazed range land which fills the river channel at an alarming rate.

There is a lot of evidence to prove that the bed of the Cauvery river in Trichinopoly and Tanjore districts has gradually risen. Many of the old irrigation sluices and drainage inlets are blocked by accumulation of sand in the river bed. The unprecedented floods of 1924, caused very extensive breaches in the flood embankment of the river by over-topping and large extents of very fertile wet lands got sanded to a depth of 2 to 3 feet. The Government had to spend several lakhs of rupees in closing breaches and restoring the flood banks. The effect of the Mettur Reservoir has been to stop some of this inflow and it is seen that the Cauvery and the Vennar below the Grand Anicut at any rate are gradually scouring again.

The immediate effect of destruction of vegetation and soil protective covering may not be appreciable, but the ultimate result is disastrous.

Damages to irrigation works.—The following case of threat of damage to the upper Jhelum canal is mentioned by *Gorrie* (1935): The Upper Jhelum canal which irrigates extensive tracts in the Punjab is aligned on contour along the northern and southern flanks of the Pabbie hills before it emerges into the plains. Soil erosion on the Pabbies affected the canal in two ways; first by the very heavy deposit of erosional debris brought into the canal by four big torrents which cross the canal by means of " level crossings "; secondly by danger of bursting of the syphons by which the smaller torrents are led under the canal bed to lower levels. These syphons were unfortunately

built in brick arch, and so they are not able to stand the high uplift pressure from within, such as is met with when the torrents heavily laden with silt come down in spate. In order to prevent the bursting of the syphons, the canal has to be always run at F.S.L. during monsoon season in order to keep up the pressure on the outer side of the syphons. From 1913 onwards some forest reclamation work on the Pabbies was attempted; but nothing systematic was done with the result that in 1931, the silt deposited in the canal increased to such an extent that the canal lost 40 per cent of its capacity. In that year four silt ejectors had to be installed in the canal at a considerable expense. These have arrested further silting of the canal, but still its carrying capacity is much below its design. The canal is also faced with danger from another group of torrents on the south-east which carry unusual runoff, sometimes with a flood peak of 1,600 cusecs per square mile of catchment.

Comparative runoff data from reclaimed and eroding land since the canal was built are available. These torrents have been classified according to their runoff intensity in cusecs per square mile of catchment. The torrents draining from the Gujar grazing lands have a peak of 1,600 cusecs per square mile. The figures for torrents coming from the north vary according to intensity of grazing. From fairly protected catchments the flood intensity varies from 600 to 700 cusecs per square mile. In the case of completely reclaimed and protected area the discharge from the torrents seldom exceed 100 cusecs per square mile. One point of importance about these reclaimed fields or *nullas* * is, that they can be cultivated even up to the very edge of the narrow stream bed, whereas in the case of uncontrolled streams, margins up to half a mile from the deep bed are left uncultivated on account of danger and damage to crops due to sudden peak floods.

During the two floods of 1936 for rainfalls of 3·70 inches and 2·70 inches, discharges and erosional debris carried by one of the torrents, viz., the Jaba Khas were measured by the Punjab Irrigation department. The entire catchment of this *nulla* is 62 square miles. The following statement gives the details:—

Volume of flood in cusecs.	Total silt content.	Silt content coarser than 0·075 m.m. in diameter.	Silt carried in one hour.	
			Total.	Coarse.
	PER CENT.	PER CENT.	TONS.	TONS.
11,200	1·15	0·18	23,000	3,600
27,750	2·04	0·30	102,000	15,000

These figures show how rapidly the carriage of silt increases with intensity of runoff. Out of the total silt carried, a greater portion

* Meaning water courses.

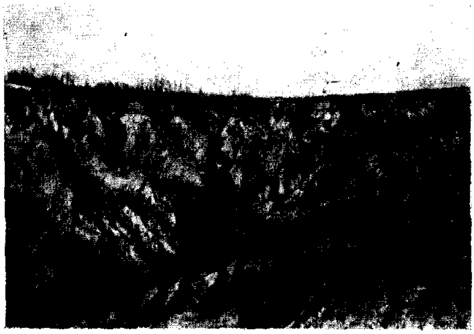


Fig. 25

(*See* below)

Fig 26

Figs. 25 and 26—Illinois, U.S.A.—Pair of photographs showing the Borgsmiller gully before and after planting with black locust

(Taken from *The Rape of the Earth* by *G. V. Jacks* and *R. O. Whyte*)

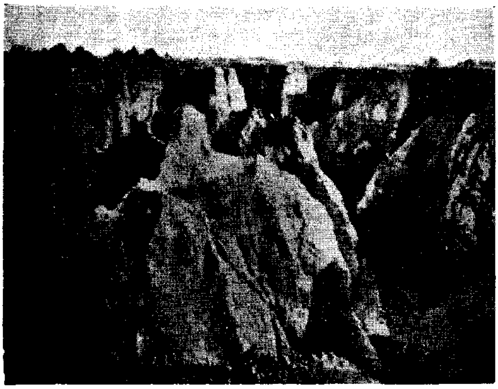


Fig. 27—GULLY EROSION IN SOUTH CAROLINA

More than 40,000 tons of soil were washed from this gully in less than eight years.

(Taken from *The Rape of the Earth* by *G. V. Jacks* and *R. O. Whyte*)

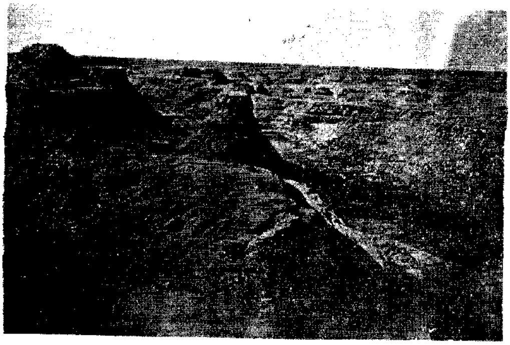


Fig. 28—EXAMPLE OF SEVERE WIND EROSION IN CENTRAL ASIA

(Taken from *Seistan—A memoir of the History, Topography, Ruins and People of the Country*)

Fig. 29 SAND DRIFT, COIMBATORE-METTUPALAIYAM ROAD

Note effect of broken fence of *Euphorbia* (*kalli*) in checking the sand resulting in small dune formation

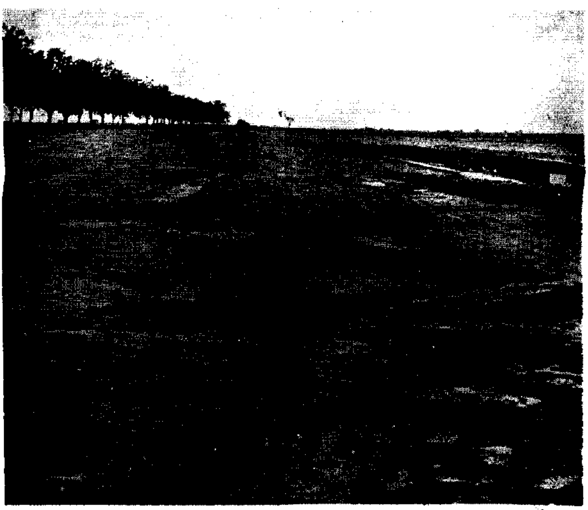


Fig. 30—SHEET EROSION AFTER A FOUR-INCH RAIN

Fig. 31 —Sheet erosion in black soils

Fig. 32— Starting of gully erosion

Fig. 33—Gullying in black soils

Fig. 34—Bad gully erosion

Surface soil washed off and the land cut up

is colloidal and is carried away in suspension to the fields or to the sea. Out of the balance there is sufficient left to upset the canal gradient and even to choke up the main river as is seen from the way in which the Jhelum City is continually threatened by flooding due largely to the raising of the river bed in the neighbourhood of the city. The maximum discharge registered for this catchment of 62 square miles is 56,600 cusecs which gives a peak flood discharge of 915 cusecs per square mile of the catchment.

Runoff from another catchment area of 228 square miles draining through seven other canal syphons in the Pabbie range from gently sloping land suffering from sheet erosion showed that floods prior to 1921 registered a peak flow of 94 cusecs per square mile. After much of the land has been brought under terracing the runoff has been reduced to a negligible quantity as no floods have been reported from this area afterwards.

Silting up of reservoirs.—In the Madras Province there are a large number of tanks which are used as storage reservoirs for irrigation purposes. Many of these tanks have been in existence from a very long time. An examination of the silt levels of these tank sluices constructed at the time the tanks were formed goes to show that these tanks have got considerably silted up from the debris brought down by the runoff from their catchments.

It is also known that the bed of the Cumbum tank has silted up about 13 feet out of a total depth of storage of 60 feet in a couple of centuries, and Maithalamannadikulam tank in Madura has nearly silted up to the crest of its weir and is in danger of obliteration on the same account.

Systematic study of silting up of reservoirs in India is engaging the attention of the Central Board of Irrigation, Simla. The following statistics taken from the list published in *Bulletin No. 27 of the Central Board of Irrigation*, regarding some of the reservoirs in India will be of interest:—

Name of reservoir.	Catchment area in square miles.	Storage capacity at the time of construction in feet.	Years of capacity surveys. First.	Last.	Period in years.	Silt deposit in feet.	Total depletion in storage to date of survey.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		ACS.				ACS.	PER CENT.
1 Gangae (United Provinces).	7,199	80,900	1915	1939	24	26,309	32·5
2 Lachura (United Provinces).	3,420	29,157	1908	1939	31	6,218	21·3
3 Pahari (United Provinces).	3,026	64,334	1911	1939	28	29,073	45·2

Name of reservoir.	Catchment area in square miles.	Storage capacity at the time of construction in feet.	Years of capacity surveys. First.	Last.	Period in years.	Silt deposit in feet.	Total depletion in storage to date of survey.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		ACS.				ACS.	PER CENT.
4 Ghaggar (United Provinces).	310	123,684	1919	1938	19	No tendency to silt.	
5 Lake Fife (Bombay).	196	90,056	1870	1940	70	19,801	22·0
6 Ekruk tank (Bombay).	159	76,446	1890–91	1923	32	10,368	13·6
7 Nehr tank (Bombay).	59·55	11,998	1896	1923	27	2,600	21·7
8 Maylai tank (Bombay).	54	4,329	1891–92	1922–23	31	2,607	60·2
9 Muchukundi tank (Bombay).	26	16,152	1890–91	1924–25	34	2,610	16
10 Matoba tank (Bombay).	10	5,255	1878	1941	63	1,010	19·2
11 Koregaon tank (Bombay).	7	2,404	1891–92	1925	33	487	20·2
12 Meiktila tank (Burma).	240	30,301	1896	1936	40	7,091	23·4
13 Tagundaing (Burma).	51	4,290	1929–30	1936	6	379	11·2

American books on soil erosion quote several instances of rapid silting up of reservoirs in America. In Southern Piedmont thirteen reservoirs have been completely filled in an average period of less than 30 years (*Eakim*). Rapid silting is in progress in Texas, Oklahoma, Arizona, Georgia, and North and South Carolina.

Lake Austin Reservoir in Texas was constructed in 1893 and failed on 7th April 1900. Its original capacity was 51,900 acre feet. Three months before it failed a survey revealed that owing to silt deposit the water capacity of the lake had dropped to 25,777 acre feet or 52 per cent of the original capacity showing that in the brief period of 6·75 years of its existence 48 per cent of its original capacity had been lost (*Edgecombe*).

According to *Bennett* (1939), the Hardinge Reservoir in Orange County, California, was completely filled with soil debris by a twenty-four hour rain in November 1926. Burning of the bush protection on the steep hill sides caused that disastrous flood. It is reported that on adjacent areas where the bush was undisturbed, the rain caused no trouble.

The following are some examples of reservoir siltation studies made in the United States of America. These are abstracted from *the Central Board of Irrigation, India, Publication No. 24* (pages

155–156). It is seen that the capacities of many important reservoirs have been considerably reduced:—

Name. (1)	Location. (2)	Age at time of survey, years. (3)	Original capacity, acre feet. (4)	Silt volume, acre feet. (5)	Total depletion of storage to date of survey. (6)
	(1) *Water Supply Reservoir.*				PER CENT.
Bay-view Reservior.	Burmingham Ala ..	24·6	11,866	2,352	19·82
Lake Michie ..	Durham N. C. ..	8·75	12,671	395	3·12
Guthrie Reservoir ..	Guthrie, Okla ..	14·5	3,064	456	14·88
White Rock Reservoir.	Dallas, Tex ..	25·0	18,158	3,882	21·38
Gibraltor Reservoir.	Santa Barbara, Calif.	16·25	14,500	4,325	29·83
Morena Lake ..	San Diego County, Calif.	25·67	68,388	7,184	10 50
Lake Osborne ..	Osborne, Kans ..	1·5	300	300	100·0
Mission Lako ..	Hoston, Kans ..	13 0	1,852	289	15·60
	(2) *Irrigation Reservoir.*				
Black Cannyon Reservoir.	Emmett, Idaho ..	12 0	37,659	4,037	10 72
Little Rock Reservoir.	Los Angelos County, Calif.	11·75	5,300	83	1·57
Lake Medina ..	San Antonio, Texas.	23·8	318,703	6,265	1 97
Elephant Buttee Reservoir.	Hot Springs, N. Mex.	20·25	2,638,860	365,186	13·84
San Carlos Reservoir.	Coolidgedam, Ariz.	6·33	1,247,999	36,896	2·96
	(3) *Power Development.*				
Lake Tennycomo ..	Branson, Mo. ..	22·4	43,980	22,266	46·08
High Rock Reservoir.	Salisbury, N. C. ..	7·8	289,432	13,916	4·81
Lay Reservoir ..	Sylacauga, Ala. ..	22·3	156,525	18,005	11·50
Lloyd Shoals Reservoir.	Jackson, Ga. ..	24·33	112,538	13,960	12·40
Byllesby Reservoir	Byllesby, Va. ..	23·66	8,892	5,354	60·21
Washington Mills Reservoir.	Fries, Va.	33·5	2,954	2,443	82·70

The efficiency of a reservoir will be greatly diminished after its storage capacity is reduced by one-half. In the case of a city water-supply reservoir, it must be abandoned and replaced by another at a great cost.

Any reservoir, pond or lake, natural or man-made becomes filled in time because of the irresistible downward flow of soil material due to gravity. In nature undisturbed it is estimated that filling will occur at a rate of one foot in three hundred years. In comparison, man-made reservoirs are silting with highly destructive rapidity. This is a question which has to be seriously studied before construction of any reservoirs is undertaken.

The following statement gives the estimated erosion deposits in flood control reservoirs in America in one storm from February 28th to March 3rd, 1938 [5 (*b*)] *:—

Reservoirs of flood control dam.	Stream.	Erosion debris deposits in one storm. Cubic yards.	Percentage of original capacity.
Pine Canyan ..	San Gabriel	4,840,000	5
Devil's Gate ..	Arroya Seco	1,935,000	25
Big Santa Anita	Big Santa Anita	589,000	34
Sawpit ..	Sawpit	176,000	33
Little Santa Anita	Little Santa Anita	68,000	77

During the same storm erosion deposits from burned water sheds of areas from 20 square miles to 1·84 square miles were collected in storage basins and these quantities estimated. Results of observation in fifteen such basins showed an average deposit of 68,733 cubic yards of debris per square mile of burned catchment area. This works out to a loss of 0·8 inch depth of surface soil during one storm. In unburned watersheds the loss has been estimated to be only 3,670 cubic yards per square mile for the same storm [5 (*b*)].*

Scanty dry-weather flow.—The result of excessive direct runoff on account of removal of vegetative cover from soil surface has been explained in the previous paragraphs. The adverse effect of soil denudation on percolation will be considered now.

Rain, as it precipitates on the surface of the ground, is disposed of in three ways, viz., (1) by direct runoff into rivers, streams, lakes and thence to the sea; (2) by percolation into the ground; (3) by direct evaporation into the atmosphere or through plant transpiration.

Part of the rain water falling on the ground soaks into the ground and wets the upper layer of the soil, the thickness and permeability of which may vary in different localities. The water so absorbed by the soil follows a downward course as far as it can until it meets some impervious layer or a non-porous rock. If no such obstruction is met with it percolates down to a depth where there is already water which has accumulated during centuries and which has not been depleted. This latter is called the "permanent water-table." As more rain precipitates more water reaches this underground reservoir until gradually, the level of the water table rises to the upper limit.

Trees in forests shed their ripe leaves which perish and constitute the spongy litter. This and the grass cover of pasture lands check the flow of rain water on sloping land. Farming practices developed primarily for prevention and control of soil erosion, have established their usefulness in conserving water in the land. Checking the flow

* The number within brackets refers to the reference in the bibliography.

of water encourages its absorption by the soil. This is due primarily to the water being held in contact with the soil for a longer period. i.e., a longer time being available to soak. This gives both gravity and capillarity fuller scope to do their work. Absorption is increased thereby and runoff is reduced; with increased absorption greater percentage of rainfall is held in the pores of the soil, and this has a very beneficial influence on crop yield in farm lands. It further raises underground water table and facilitates its utilization by pumping or baling for irrigation purposes.

Experiments carried out in the Punjab in the Siwaliks on small catchments of 25 acres go to prove that good soil conservation methods have resulted in reducing percentage of runoff [5 (*d*)].

The curve in Fig. 51 shows the effect that deforestation or eliminating the humus on the surface of the soil has on the absorption of rainwater into the soil.

It is estimated that in the scarcity areas of Madras and Hyderabad (Deccan) 10 to 30 per cent of the total annual rainfall is lost as runoff on account of lack of proper anti-erosion and rainfall conservation methods.*

The following information taken from *U.S. Department of Agriculture, Miscellaneous Publication* No. 253 will give instructive information regarding plant cover and runoff:—

Studies carried on near Ithaca, New York, by the Soil Conservation Service in co-operation with Cornell University, show that during one growing season a single acre of cornland lost as runoff 172,900 gallons (6·37 acre feet) more water than was lost from an acre of comparable meadow land on another part of the same slope.

Water losses observed on the watershed of one of the tributaries of the Susquehanna River near Ithaca just before the floods of March 1936 showed that a potato field lost 88 per cent of the total precipitation on land having a slope of 14 per cent. Out of 9.47 inches of rain and snow received in March 1936, 8·38 inches was lost as runoff. In contrast water loss from a neighbouring forest area with a slope of 27 per cent was approximately 0·5 per cent. From neighbouring grass land with a slope of 20 per cent the runoff was less than 0·2 per cent.

At the Erosion Experiment Station, Zansville, Ohio, on a 12 per cent slope in a section with an average rainfall of 34·5 inches, measurements for a period of 2 years showed that 42·5 per cent of the total rainfall and snow on bare ground was lost. Where the land was planted continuously to corn, 35·2 per cent of the precipitation was

* Proceedings of the 3rd meeting of the Crops and Soils Wing of the Board of Agriculture and Animal Husbandry in India, page 79.

lost as runoff, but on the same ground where a four-year rotation of corn, wheat and 2 years of grass was practised the runoff amounted to only 18·4 per cent of total rainfall and snow. A blue grass area of exactly the same kind of land lost only 4;5 per cent of rainfall.

Measurements over a five-year period at the Erosion Experiment Station near Bethany—Mo. on Shelby loam soil with land of 8 per cent slope showed that 31·2 per cent of average and 34·8 inches of snowfall and rain on fallow land was lost as runoff. Land planted to blue grass and timothy lost only 9·3 per cent of the total rainfall. Land planted continuously to corn lost 28·3 per cent of the precipitation.

Springs and wells are fed by reserves of water stored in the subsoil underground. If these reserves dwindle, then wells dry up, springs are reduced to a trickle and rivers that once flowed perennially fail altogether during dry periods. Irrigation schemes that are dependent on perennial flow in the streams will suffer during dry weather for want of sufficient water if the catchments are not capable of conserving rainfall.

CHAPTER III

CHIEF CAUSES OF ACCELERATED EROSION IN AGRICULTURAL SOILS

Let us examine the chief causes of accelerated erosion in cultivated lands. If all the rain-water is absorbed by the soils as fast as it is received there will be neither runoff nor erosion. This happens only in open soils such as sand, peat, etc. Most of the cultivated soils are either loamy or heavy soils. It is the incapacity of soils to absorb rain-water quickly that is responsible for surface runoff. The nature of the soil and its physical condition influence greatly the flow of water. The amount and speed of runoff waters are governed by the following factors:—

(1) Intensity of rainfall on the catchment.

(2) Size and shape of the catchment.

(3) Slope of the land.

(4) Soil variable qualities.

(5) Vegetation on the land forming the catchment.

(6) Nature and extent of the cultivation on the catchment land.

(7) Whether the area is thrown open for grazing or not.

(8) Atmospheric conditions, or rather meteorological conditions, such as temperature, humidity, velocity of wind, etc.

(9) Other miscellaneous factors, such as wrong method of ploughing, viz., along the slope instead of across the slope, causing ruts, furrows, etc.

Nature and distribution of rainfall.—The amount of run off naturally depends upon the intensity of rainfall. A heavy downpour within a short interval might cause as much damage as all the other rains during the year put together. A slow gentle shower will be absorbed by the soil easily and will cause less damage than a heavy sharp rain. In dry tracts one of the factors that contributes to excessive erosion is that there will be no crop or other vegetation on the land during most of the period when the rains are received, the crops being sown only after the rainy season. As an example we can consider the black soil areas of the Ceded districts. The main

hingari or late sown crops, cotton and sorghum are harvested by March or April. Between April and September or October, the land is fallow until the next sowings are done. The distribution of rainfall is such that out of an annual precipitation of about 20 inches, about 12 inches are received in the quarter August, September and October. It is only after the receipt of the September rains that cotton is sown, while sorghum is sown at the end of the rainy season in October. Most of the rainfall is thus received when the land is fallow or without any crop. Summer being very desiccating there is little or no vegetation on the land. In a small proportion of the area *mungari* or early crops like *setaria* or groundnut are sown in June or July; these are all the protection against erosion, to withstand the direct impact of rain on the soil. It is also common to have one or two instalments of heavy rain amounting to about 3 inches overnight during the rainy period. From the erosion point of view, conditions are worse in the coastal districts where the annual rainfall is much higher than in the Ceded districts.

Effect of land slope.—Another important factor on which the speed and extent of runoff depend is the slope of the land. The greater the slope the greater the velocity of flow of the runoff water. It has already been noted that if the velocity of the runoff water is doubled its energy is increased four times, as the latter varies as the square of the velocity.

(*a*) According to the law of falling bodies, velocity varies as the square root of the vertical drop. Hence if the land slope is increased four times, the velocity of the water flowing on the slope is doubled approximately.

(*b*) If the velocity is doubled, the erosive or cutting capacity as represented by the Kinetic Energy is increased about 4 times as K.E. $\propto \frac{v^2}{2g}$.

(*c*) If the velocity is doubled, the quantity of material of a given size that can be carried is increased about 32 times (amount $\propto V^5$).

(*d*) If the velocity is doubled, the size of the particle that can be transported by pushing or rollling is increased by about 64 times (size of particle $\propto V^6$).

(*e*) There is a definite limit to the amount of silt that can be carried in suspension due to the action of cross eddies in water flowing at a given velocity and depth. When this limit has been attained, more material cannot be picked up no matter how erosive it is without increasing the velocity or depth. Any reduction in velocity or depth will result in deposition of silt.

(*f*) For a given volume of water, the depth depends on the extent of lateral irregularity in slope and in erosive properties of the soil. When water flows in rather definitely defined channels, there is reduction in friction and a still greater increase in velocity.

Land slopes cannot be directly changed but can be modified in their effect on runoff by the use of transverse channels or terraces or by bunding along contours. By these methods, long slopes are divided into a series of short units, thus minimising the velocity and the resulting runoff.

The undulating nature of the cultivable land in the Ceded districts contributes its share in increasing erosion losses. The chief factors underlying accelerated erosion in heavy soils of the plains are thus the nature of the soil, which does not allow a quick penetration of rain water into the soil, the undulating nature of the lands and the absence of any protective cover of vegetation during the rainy period.

The hilly tracts of the Nilgiris are subject to severe erosion during the rainy period. Cultivation of potatoes is done on very steep slopes without adopting proper anti-erosive measures. After the harvest of potatoes in July-August the soil is left in a loose condition. In such fields erosion has been particularly severe as there is no cover crop to protect the soil from being washed away. When land is newly brought under cultivation the natural cover of grass is removed and this greatly increases erosion losses as will be shown in the succeeding paragraphs. Slope and physical condition of the soil combined with heavy rainfall contribute to heavy erosion losses in the hilly areas.

Classification of soils.—Based on the size of component particles, the farmer recognizes light or sandy soils and heavy or clayey soils. Soils are classified according to the ultimate size of their mineral particles. In the international method of mechanical analysis adopted in Great Britain in 1928 [*Comber*, 1932] the division of the soil into the following components has been recognized:—

Name of fraction.	Effective diameter in mm. MAX.	MIN.	Method of separation.
Coarse sand	2·000	0·200	Sieving.
Fine sand	0·200	0·020	Residue from decantation.
Silt	0·020	0·002	Pipetting.
Clay	0·002	..	Do.

The general principles adopted in the mechanical analysis of soils by the international method is as follows:—

After sieving the soil through a 2 mm. sieve, the sample is dispersed in water to which a little ammonia is added for affording

complete deflocculation of the colloidal material. The rate of settling of particles in suspension is proportional to the square of the effective radius of the particles. Therefore the coarse sand settles out first while the clay, which is the finest fraction, remains in suspension for a long time. The rate of settling depends also on the temperature of the suspension. By an application of Stokes' Law [*Wright*, 1934] which gives the relation between velocity of the settling particles and their diameter at different temperatures, the amount of clay and silt can be determined by pipetting to a depth of 10 cms. after allowing the suspension to settle for different periods. After pipetting for silt and clay the sample is decanted until a clear suspension is obtained. The material is then sieved through a 0·2 mm. sieve for coarse sand and fine sand. (For details of the determination of mechanical analysis of soils, please see *Wright*, 1934.)

The mechanical composition of a few heavy, medium and light soils occurring in the Madras Presidency are given below:—

Place.	Type of soil.	Clay.	Silt.	Fine sand.	Coarse sand.
		PER CENT.	PER CENT.	PER CENT.	PER CENT.
Siruguppa, Bellary district.	Clayey or *heavy soils* ..	58·6	13·2	10·6	9·2
Hagari, Bellary district.	Do. ..	44·9	17·1	15·7	17·5
Coimbatore, Coimbatore district.	Loamy or *medium soils.*	26·3	28·3	18·7	16·8
Koilpatti, Tinnevelly district.	Sandy or *light soils* ..	27·6	3·9	18·4	49·7
Palakuppam, South Arcot district.	Do. ..	18·3	2·4	27 6	51·8

As the names suggest, the heavy soils have a high proportion of the finest fractions, viz., clay and silt, while the light soils have a high proportion of the sand fractions. We have the loamy soils intermediate between the two extremes. The two terms do not relate to the weights of equal volumes of soils but to the ease with which cultivation can be done.

Nature of soil in relation to erosion.—Heavy soils like the black cotton soils of the Ceded districts are highly susceptible to erosion. They are rich in fine fractions, viz., clay and silt. It is the fine colloidal clay that determines all soil-water relations. It is highly retentive of moisture, but on account of the heavy nature of the soil, it is slow to absorb rain water. It is sticky when wet and hard when dry. These black soils are similar in many respects to the extensive group of black earths known as "Chernozems", one important difference being, however, that the "Chernozems" are rich in organic matter, while these soils are poor, consisting of 1 to 2 per cent of organic matter. The colloidal clay which might be visualised as a

thin film existing round the mineral particles swells on wetting and restricts the capillary passages in the soil. Clay when flocculated assists in the formation of compound particles. This aggregation into compound particles is known as " crumb structure " and is from the agricultural point of view the most desirable structure. It offers the least resistance to the passage of implements and allows water to percolate to lower layers. But when the rain drops begin to beat on the crumbs or compound particles, there is pulverizing action which results in the deflocculation of the colloids of the soil. Flocculation is assisted by the presence of electrolytes in the soil and when these are washed away due to excessive leaching of the soil, deflocculation of the colloids sets in. [*Russel*, 1935.] The crumbs deteriorate and the soil-water mixture flows on the surface as a viscous fluid. Consequent on the loss of structure the fine material flows into the pore spaces of the soil clogging them and preventing any further percolation of rain water to the lower layers. The soil will thus be incapable of absorbing the rain water as fast as it is received resulting in runoff which carries away the surface soil with it.

Effect of vegetation.—Plant life plays an important role in soil and water conservation and acts in the following ways:—

(*a*) Direct dispersion, interception and evaporation of falling rain by the foliage of trees and shrubs.

(*b*) Transpiration of vast quantities of moisture from the sub-soil back into the air through the body tissues and leaves of the plant.

(*c*) Protective shield afforded by the close growing grasses and cover crops against violent impact of rainfall.

(*d*) Knitting and binding effect of the root system in surface layers of soil simulating a sponge like condition.

(*e*) Penetration of roots into the soil which decay and leave numerous tubular cavities to promote infiltration of water.

(*f*) Improvement of soil structure by addition of organic matter which increases absorption of moisture and keeps the soil in a condition suitable to support vigorous plant growth.

(*g*) Increased surface friction which reduces volume and velocity of runoff.

(*h*) Surface friction which tends to keep water spread out laterally and thus delays the rate of concentration in tributary drainages.

(*i*) Addition of humus to the soil which facilitates entry of air into the soil and creates a more favourable environment for beneficial bacterial activity.

In symbol form, $E = \text{function } (R.G\ S.V.)$ i.e. $E \propto \int R.G.S.V.$ where

E=Rate of erosion.

R = a factor depending on the amount and intensity of the rainfall.

G = a factor depending on the slope and area of the land.

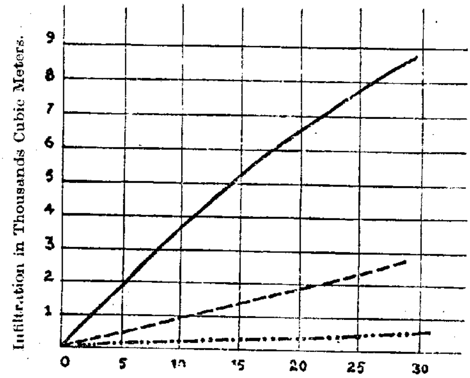
S = a factor depending on the physical and chemical properties of the soil.

V = a factor depending on the extent and volume of vegetative cover.

It is well worth remembering the above principles in combating the wasteful runoff and soil erosion.

From the results of experiments conducted in the Sholapur Dry Farming Research Station, it is seen that about 20 per cent of total rainfall is lost by runoff which erodes away 35 tons of soil per acre per annum in the Bombay-Deccan tracts. In other words $\frac{1}{6}$ inch of soil is lost per annum by erosion or 1 inch of soil in six years. In light soils where the depth of soil does not exceed 6 inches the entire

Fig. 37—Effect of cover on infiltration



———— Undisturbed forest with developed litter.

- - - - - - - Disturbed forest with undeveloped litter.

—..—..— Clear-felled forest with heavy erosion pavement

soil will be lost by erosion in about 36 years leaving the hard *muram* subsoil bare and unfit for any crop. Geologically, it takes thousands of years for nature to convert rock into soil 1 foot deep, fit for cultivation, but it is completely eroded and lost in about 50 to 100 years.

Measurements of runoff and erosion in Missouri Experiment Station, Columbia, U.S.A.

(Average of 14 years)

Soil type, shelby loam; length of slope, 90·75 feet; slope, 3·68 per cent.

Cropping system or Cultural treatment.	Average annual erosion per acre in tons.	Percentage of total rainfall running off the land.
1 Bare, cultivated, no crop ..	41·0	30
2 Continuous corn	19·7	29
3 Continuous wheat	10·1	23
4 Rotation—Corn, wheat and clover	2·7	14
5 Continuous blue grass ..	0·3	12

Measurements of runoff and erosion taken from the Forest Department Research Station, Punjab.

(Slope 25 per cent)

Particulars for 43 inches rain in 135 wet days.	Kind of vegetation.		
	Grass bush 90 per cent cover.	Grass 80 per cent cover.	Almost bare soil 10 per cent cover.
Percentage of water lost by runoff.	9·16	14·55	47·51
Weight of soil lost by runoff eroded per acre.	4,978 lb. or $2\frac{1}{4}$ tons.	4,861 lb. or $2\frac{1}{4}$ tons.	44,175 lb. or 20 tons.

In the Sholapur Agricultural Research Station [1] in the Bombay Presidency experiments were conducted to obtain runoff data from various experimental plots each plot being 1/80 of an acre in extent. These plots were located on an area having a slope of 1 in 85. The soil is ordinary Deccan black cotton soil 9 to 18 inches deep obtained from disintegration of Deccan trap. An analysis of the soil showed the following particulars: Clay 58·49 per cent, silt 26·86 per cent and fine sand 11·67 per cent. Eight plots were selected for observation and experiments were carried on for five years, i.e., from 1933-34 to 1938-39. The following are the details of treatment of the plots:—

Plot No. 1.—Retention of natural vegetation.
,, 2.—Natural vegetation removed by cutting.
,, 3.—Shallow cultivation by harrowing.
,, 4.—Thorough and intensive cultivation by ploughing and harrowing and growing *rabi* crop of *jowar*.
,, 5.—Scooping of the surface soil after cultivation.
,, 6.—Thorough cultivation by ploughing and harrowing and growing *kharif bajri* and *tur* mixture.
,, 7.—Thorough intensive cultivation by ploughing and harrowing but without a crop on it.
,, 8.—Thorough intensive cultivation as in plot 7 but the plot is of double the length.

The average percentage of runoff as calculated from observation carried out for five years is given below:—

Year.	Average rainfall in inches per year.	Runoff percentage. Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.
1934–39	25·96	3·44	15·50	18·34	16·61	7·22	13·48	16·08	16·7

The following table gives the average quantity of soil lost in tons per acre per annum:—

Year.	Average rainfall in inches per year.	Rainfall in inches causing runoff.	Soil lost in tons per acre. Plot 1.	Plot 2.	Plot 3.	Plot 4.	Plot 5.	Plot 6.	Plot 7.	Plot 8.
1934–39.	25·96	14·09	0·215	27·05	39·02	57·55	20·71	37·12	52·30	40·71
Number of years required to erode top 8″ of cultivable soil			4,146·0	32·92	22·84	15·48	43·01	24·01	17·04	21·90

In plot 1 the natural vegetation was allowed to grow. This was very little in the beginning. Afterwards there was fair growth of ordinary vegetation found in black cotton soil areas. This vegetation would dry up during summer and again take growth during rainy season. Practically all the rain of the season would fall between June and October. Runoff percentage from plots 1 and 5 was very little, compared with the runoff percentage from other plots among which there is very little variation. Erosion loss from plot 1 is practically very little.

It was found that after five years, the average slope of the ground which was 1 in 85 before the experimental beds were laid deteriorated to 1 in 60. The increase in gradient is likely to increase the rate of erosion and runoff.

The rain falling on a dry area is spent as follows:—

(i) By surface runoff.
(ii) By evaporation.
(iii) By underground drainages.
(iv) By plant growth itself.

Ordinarily, it will be difficult or impossible to reduce water lost by items (ii) and (iii) above. But it is possible to prevent or reduce surface runoff and thereby increase water available for plant growth and good crop production.

From agricultural researches it is seen that about 400 lb. of water is required for every 1 lb. of dry matter produced. Assuming that the normal dry crop and fodder outturn even as per scientific dry farming method is about 500 lb. crop plus 600 lb. fodder = 1,100 lb. per acre (*vide* results of Bijapur farm experiments) about 1,100 × 400 lb. or 200 tons approximately of water or 2 inches of water per acre is required for this and so it should be possible to get a good dry crop of *cholam* or *cumbu* from the lands if only 2 inches of rain can

be retained in the soil and made available for the crop in the crop season. Allowing for evaporation, and subsoil drainage and minimising surface runoff it should be possible to produce good crops even with a scanty rainfall of 10 or 15 inches per annum. This leads us to the problem of overcoming surface runoff and conserving soil and storing more water in the soil for increasing crop production. Surface runoff and soil erosion are taking place every time there is rainfall. These are the greatest enemies of dry crop cultivation and of national well being. Hence combating them should be considered as a national problem and remedial measures must be taken on a wide scale.

Measurement of losses due to sheet erosion.—Losses of soil and water due to sheet erosion can be measured with a fair degree of accuracy although the variables involved are numerous and exert great influence on the actual amount of runoff. The chief factors that influence the amount of runoff are, as we have seen, the slope of the plot, the nature of the soil and its physical condition resulting from the cultivation that it has received, the nature of the plant cover and the nature of the rainfall. Under given experimental conditions it is always possible to measure the quantity of runoff. The magnitude of the losses can only be realized from quantitative measurements. Experimental studies were made on black cotton soils of the Ceded districts at very gentle slopes, during the last six years, at the Dry Farming Station, Hagari [*Subba Rao*, 1940].

Experimental technique

Two plots 66 feet X 8¼ feet (area 1·25 acres) with a gradient of 1 in 80 were selected. On three sides the plots were enclosed by galvanized iron sheets which project about a foot above the ground level. The plots were thus thoroughly isolated from the rest of the area and the runoff was collected into masonry cisterns (6 feet × 4 feet × 3 feet) towards which the plots slope (*see* Fig. 42 for a picture of the runoff plots). The volume of the mixture of soil and water that collected in the runoff plots after each rain was measured. Samples of runoff were analysed for water and soil content separately. A sample sheet of calculations for arriving at the actual losses of soil and water is given at the end of this chapter.

Any method by which the velocity of the runoff water could be minimised helps in the reduction of erosion losses. If small pockets or basins are formed it will be effective in checking erosion. The effect of "scooping"—as this practice of forming basins is called—on the control of erosion was also studied. One of the plots had scoops formed in it before the rainy season, while the other was given

hand hoeing and kept as clean fallow. The latter served as "control." Some typical results obtained in these plots are given in the following table:—

***Runoff results*, 1937–39.**

(Blacksoil, Hagari, Bellary district; gradient of the plots, 1 in 80; rea of each plot, 1·25 acres.)

	1937-38.	1938-39.	
	Average of two control plots both kept clean fallow.	Control plot.	Scooped plot.
1 Number of days when there was runoff	11	13	10
2 Total rainfall on days when there was runoff in either plot, in inches	9·16	15·66	15·66
3 Rain water lost in inches ..	4·00	7·52	3·29
4 Rain water lost expressed as per cent of rainfall received ..	43·67	48·01	21·01
5 Silt washed off in tons per acre ..	6·58	9·86	3·60
6 Silt washed off in tons per acre per inch of rainwater lost ..	1·65	1·31	1·09

It is seen from the above data that in the "control" plot, which was clean fallow, 44 to 48 per cent of the rain water was lost by surface flow during the two years 1937 and 1938. Considerable amounts of silt were lost in the runoff waters. The soil losses amounted to 6·6 and 9·9 tons per acre for a rainfall of 9·2 and 15·7 inches respectively in the two rainy seasons. Every inch of rain water that is lost from the soil as runoff, carried with it on an average 1·5 tons of silt per acre during the two years.

While the actual amount of runoff depends on the intensity of rainfall and the slope of the plots, some of the American results reported from the Texas Experimental Station on runoff under agricultural conditions were 3 tons of soil per acre per inch of rain water lost [12]. Grass was found to be 65 times more efficient in the control of soil losses and five times more effective in checking water losses than bare soil.

At the Dry Farming Station, Sholapur (Bombay), it was found that a clean fallow plot—size being the same as those described above—lost 25 tons of soil in one year for a rainfall of 14·8 inches when the runoff was only 5·8 inches. The soil removed per inch of water lost was 4·3 tons per acre, while the corresponding figures for Hagari (Madras) were 1·6 tons per acre during 1937 and 1·3 tons per acre during 1938. A plot in which weeds were preserved gave only 0·58 ton per acre or 1/50th of the losses in the clean fallow plot at Sholapur [4]. On an average at the gentle gradient of 1 in 80, about 8·25 tons of soil per acre were lost by erosion from a clean fallow plot at Hagari, i.e., about 16 cart-loads of fine silt.

Fig. 38—Overgrazed scrub jungle in an unfelled area which is open to unrestricted grazing

Note that in this case the bank bordering a stream has collapsed, resulting in a serious loss of top soil

(Photo by *J. A. Wilson*)

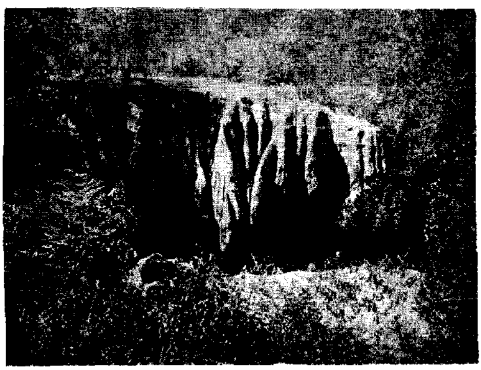


Fig. 39—Scour resulting from annual floods in a stream in Panapakam Reserved Forest of Chittoor district

The catchment is dry scrub jungle, badly overgrazed. The curious formation is due to the pulverizing effect of heavy rain combined with runoff from adjacent areas which scours out the gullies

(Photo by *J. A. Wilson*)

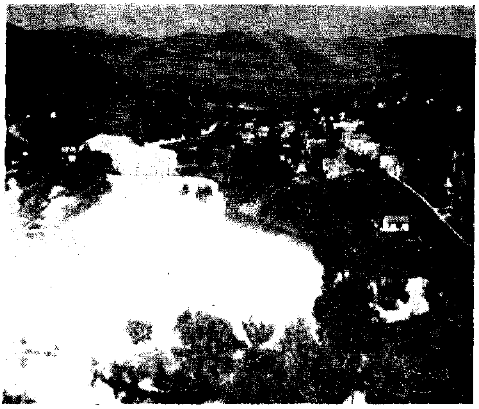


Fig. 40

(*See* below)

Fig. 41

Figs. 40 and 41—MINNESOTA, UNITED STATES OF AMERICA
LAKE COMO

Photos taken in 1926 and as silted up in 1936. The silting is reported to be due to farmers up river cutting timber, cultivating more of the hill slopes and leaving less vegetation to retard runoff. At times the silt was so thick in the lake that most of the fish and other marine life were killed

(Taken from *The Rape of the Earth* by *G. V. Jacks* and *R. O. Whyte*)

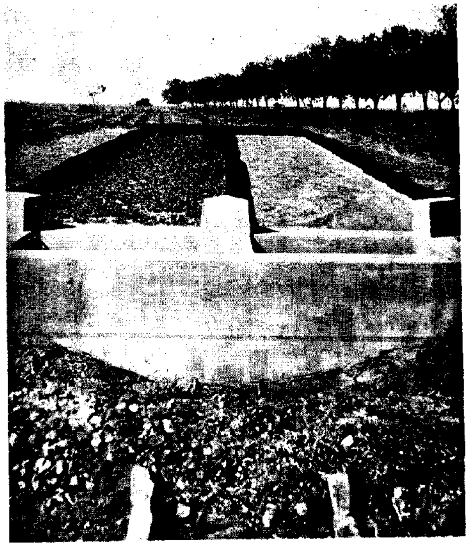


Fig. 42 Runoff plots at Hagari with and without cover crop of groundnuts

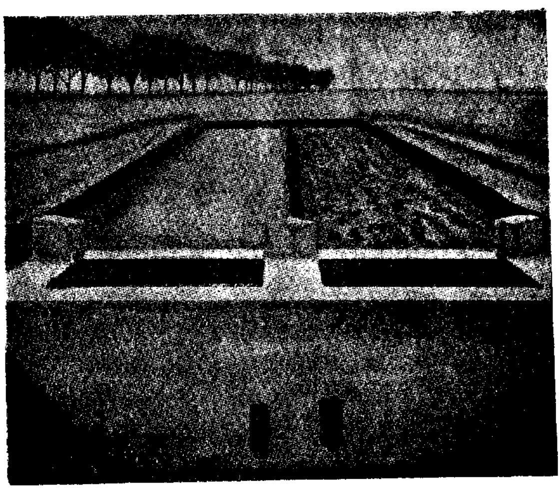


Fig. 43 Runoff plots at Hagari—Control and scooped plots

Fig. 44—HAGARI WIND BELT

Photograph taken in May 1943. This belt is on the margin of the River Hagari seen in the right background and was planted in 1942

(S. V. Rao)

Fig. 45—HAGARI WIND BELT

(Photograph taken in March 1944)

Intense storms contribute most to runoff. A single storm on the 28th/29th September 1938, for example, was responsible for nearly a third of the total loss of silt and a fourth of the total loss of water that occurred during the whole year, as shown below:—

		Rainfall in inches.	Water loss in inches.	Soil loss in tons per acre.
28th/29th September 1938	..	3·57	1·81	3·29
Whole rainy period of 1938	..	15·66	7·52	9·86

Such instances are common when the scouring action of an intense storm does great harm and removes much of the valuable surface soil. It is stated that in one intense storm with a 5-inch fall the rich soil of the Texas Black Belt which is similar to the black soil of South India lost 23 tons per acre from a very slight slope [*Gorrie*, 1935].

Heavy soils shrink very much on drying, causing the formation of numerous cracks. When the soil is in this condition, even a high *precipitation does not cause much runoff.* Runoffs recorded early in the rainy season are small, e.g., on the 4th July 1939 for a rainfall of 1·14 inches the runoff was only 0·03 inch and the soil loss was 0·03 ton per acre under fallow conditions. Runoff data recorded at Hagari early in 1940–41 illustrating this point is given below:—

Runoff data recorded early in 1940–41.

Date.		Rainfall in inches.	Runoff in inches.
7th June 1940 ..	..	0·49	0·10
* 10th June 1940 ..	..	0·52	0·26
13th August 1940 ..	..	0·97	0·02
13th September 1940	..	0·87	0·04
Total	..	2·85	0·42

*(Rainfall on 10th June 1940 follows closely that received on 7th June 1940 and naturally the runoff is a little more than that recorded on the rest of the days. The interval of about a month has again dried up the soil and consequently the runoff on 13th September 1940 is low.)

Effect of scooping on the control of erosion.—Scooping or listing is one of the methods of control of erosion. By forming a series of pockets in the field the velocity of flow of runoff waters is reduced and a greater time is allowed for the soil to absorb the rain water. It is seen from the table on page 32 that by scooping, water losses were reduced from 7·5 to 3·3 inches while soil losses were reduced from 9·9 to 3·6 tons per acre in one season. Scooping the land, therefore, considerably reduces the runoff and consequent losses by erosion.

3

Data on a few occasions when the scoops were very effective in reducing the runoff is given below:

Extract of runoff data for 1938.

Date.	Rainfall in inches.	Runoff in inches. Control plot.	Runoff in inches. Scooped plot.	Silt lost in tons per acre. Control plot.	Silt lost in tons per acre. Scooped plot.
6th August 1938 ..	1·89	1·12	0·26	1·259	0·409
18th August 1938 ..	1·62	0·92	0·15	1·020	0·185
22nd August 1938 ..	2·39	1·31	0·71	1·570	0·842
24th September 1938	1·18	0·60	0·03	0·492	0·036
25th September 1938	1·81	0·39	0·09	0·215	0·032
Total ..	7·89	4·34	1·24	4·556	1·504

The reduction in the runoff in the "scooped" plot on these occasions of heavy rainfall is, as explained already, due to the mechanical obstruction to the flow of water which the scoops offer.

QUALITY OF SOIL WASHED BY RUNOFF WATERS

The soil collected in the runoff cisterns, when analysed for the physical and chemical composition, gave the following results:—

Mechanical analysis of silt collected in 1937–38.

Heads of analysis.	Runoff silt.	Soil 1st foot layer.
1 Clay	56·8	44·9
2 Silt	26·9	17·1
3 Fine sand	8·5	15·7
4 Coarse sand	1·4	17·5

Chemical analysis of silt collected in 1937–38.

Heads of analysis.	Runoff silt.	Soil 1st foot layer.
Loss on ignition	7·140	3·120
Insoluble matter	63·950	75·490
Iron and Alumina (R_2O_3) ..	20·950	13·190
Lime (CaO)	3·830	3·450
Magnesia (MgO)	1·520	0·920
Potash (K_2O)	1·280	0·290
Phosphoric acid (P_2O_5) ..	0·041	0·054
Nitrogen (N)	0·043	0·024

These figures for the analysis of silts collected in the runoff cisterns are typical of the data obtained at Hagari during different years. The analysis of the soil from the top one foot layer is also included in the above table for purposes of comparison. The figures for mechanical analysis show that the silt washed off the land consists of about 84 per cent of the fine fractions, viz., clay and silt, while the soil contains only 62 per cent. The difference is due to the fact that during the course of the washes the coarse particles settle out quickly and it is the fine material that gets lost. The nitrogen

content of silt was 0·043 per cent while that of the soil was only 0·024 per cent. Potash in the silt was about four times that contained in the soil. Thus from all accounts the silt that is washed off the land is much richer than the original soil. Much of the organic matter present in the soil gets lost; the loss on ignition of the silt being nearly double that of the original soil. The fertility of the soil is lost and a poorer soil is left behind. A healthy soil is the first essential for the production of a healthy crop. Loss in soil fertility results in a crop which is unhealthy and susceptible to disease.

SPECIMEN SHEET OF CALCULATION OF RUNOFF DATA

Let the area of the runoff plot be 1·25 cents or 1/80th acre.

Let the length of the runoff cistern be 6 feet; its breadth 5 feet: and its height 3 feet.

Total capacity of the cistern is 90 cubic feet.

Suppose there is a rainfall of 1 inch, the mixture of soil and water that collect in the cistern is of height say 14 inches: The volume of the runoff is $\frac{6 \times 5 \times 14}{12}$ cubic feet or 35 c. feet.

This consists of (1) direct rainfall that falls into the cistern ; (2) volume of silt washed off from the plot; (3) actual volume of water lost as surface runoff.

Volume of the direct rain water received into the cistern is — $6 \times 5 \times 1 \div 12 = 2{\cdot}5$ c. feet.

Volume of silt and runoff water alone is therefore 35 – 2·5 or 32·5 c. feet.

100 c. c. of the mixture is dried and the silt that is contained in it is determined — the drying being done at 105° C. Usually, duplicate determinations are made.

Let the weight of silt in 100 c. c. of the sample be: 2·46 gm. The weight of silt in the runoff waters is $\frac{35 \times 12^3 \times 2{\cdot}54^3 \times 2{\cdot}46}{100}$ gm. or W say.

The weight of silt lost in tons per acre is $\frac{W \times 100}{1{\cdot}25 \times 453{\cdot}6 \times 2240}$ or 1·920.

Silt lost per plot is only *0·024 ton*.

The real specific gravity of the silt was determined and found to be 2·35. Assuming this value for the specific gravity, the volume of silt can be calculated.

1 ton of silt occupies a volume of $\frac{2240 \times 453{\cdot}6}{2{\cdot}35}$ c.c.

Let this be V c.c.

The volume in c. feet. is: $\frac{V}{2{\cdot}54^3 \times 12^3}$ or 15·27 c. feet.

Volume of 1·92 tons of silt is *29·31 cubic feet.*

Volume of runoff water and silt from one plot of 1/80th of an acre is 32·5 cubic feet.

Therefore, volume of runoff water and silt from an acre plot will be 32·5 × 80 or 2,600 cubic feet.

Volume of silt washed per acre is 29·31 cubic feet.

Therefore, net volume of runoff water alone is 2570·69 c. feet.

Runoff in inches of rainwater is $\frac{2570{\cdot}69 \times 12^3}{4840 \times 9 \times 12^2}$ or *0·71 inch.*

The results are expressed as indicated in table on page 32.

3A

CHAPTER IV

METHODS OF EROSION CONTROL IN AGRICULTURAL LANDS

FROM WHAT has already been said it will be seen that soil erosion is the result of misuse of land and is a man-made problem. Where man has not interfered with the natural vegetative cover of the soil, erosion does not exist. But man must live by cultivating his crops and his animals must live. Certain lands are suited to cultivation, while others are not. If unsuitable lands are broken to the plough, nature steps in by causing erosion and destroys the soil. While such lands may produce crops for a few years, they eventually become sub-marginal for cultivation and finally become derelict. The basis for all soil conservation measures is the realisation of the natural limitations on the use to which land may be put and the application of these limitations in the control of land utilization. This fact is now realised in many countries and planning for better land use is the order of the day. It is now realised that in the past, many mistakes have been made in the alienation of land from public to private interests. Madras is no exception. Lands such as on the outer slopes of the Nilgiris for example should have been retained in perpetuity under natural forest cover. Such mistakes have already had their effect and have adversely affected the public interest. Planned use of land sets right mistakes of the past and makes possible a future in which the fertility of the soil will no longer be dissipated by misuse. It makes possible long term conservation planning by correlating soil science with social science into a single public soil policy.

One of the first broad divisions to be drawn in planning land use is that between soils which are to be maintained under permanent natural cover and those which may be brought under the plough. In the last chapter we studied the various factors, such as, rainfall. slopes, soils, vegetation, etc., on erosion. For erosion to take place the soil particles must be transported by water and wind. The greater the velocity of the vehicle, the greater the destruction.

Increased slope means increased velocity of runoff water and its effect is given below:—

(1) The cutting power or corrosive power increases with the square of the velocity.

(2) The size of the particle that can be carried increases with the sixth power of the velocity.

(3) The weight of material transported increases with the fifth power of the velocity.

Because of this danger it is generally unwise to cultivate lands above a critical slope varying between 1 in 4 and 1 in 7 according to local conditions of soil and climate. It is true that lands on steep gradients have been brought under cultivation in the past as is seen in Ceylon, limited areas in India, Java, parts of Peru, etc., but only after the expenditure of an enormous amount of labour in terracing, which would not be economic today. To cultivate without terracing such slopes is soil suicide.

The decision having been taken to leave sloping land under natural vegetation the next step is to see that we achieve this object. At present a large proportion of such lands still carries natural cover, but an appreciable area is cultivated. Let us consider the condition of these lands in Madras. Over the larger part of Madras it leaves much to be desired. Over large areas especially in the dry districts the natural cover has been appreciably affected chiefly by two factors which are closely related. These are fire and over grazing. The general picture is as follows: The outer foot hills carrying a light cover of dry thorny scrub jungle over a medium grass cover are also the grazing grounds for the cattle of adjacent villages. With the hot weather the grass dries up and nothing is left for the cattle which have often to go further into the interior and nearer to the steep slopes which rise to the main hill ranges. When the south-west monsoon breaks out thunder showers can be depended on. The grazier knows that if he burns the dry grass about this time, he will get a green flush of young grass in the burnt areas. This is the reason for well over 75 per cent of the forest fires. Such fires spread to the steep slopes and rush upwards with increasing intensity. Wherever a fire occurs the ground cover is destroyed, while the tree growth receives a severe set-back. The first shower falls on exposed soil resulting in runoff and sheet erosion. In the outer foot-hills where the intensity of grazing is too high, erosion again occurs through the over-grazing of ground cover. These factors have resulted in the gradual deterioration of the forests and forest pastures for many years, to such a degree, that they no longer share their proper function in the land economy of the neighbourhood. Restoration of the

original conditions necessitates their improvement by one or several of the measures described below:

Where steep lands are cultivated little has been done to protect the soil effectively. A certain amount of bunding of individual holdings can be seen here and there, but without proper terracing. These few cases usually date from many years ago when labour was cheap, and the cultivator had not been affected by the increased tempo of modern times. But in general, such measures are ineffective and little is done to maintain them in good condition. Vast areas of land about the limit of slope have been assigned for cultivation during the past 25 years. In these the usual story is one of collection of loose stones and forming them into bunds, followed by ploughing. In the first year of cultivation the topsoil is lost uncovering more surface stones which are added to the original bunds. So, gradually, a sloping terrace of subsoil is held up on which the cultivator can eke out a miserable existence by fallowing his land frequently.

Examples of such misuse of land can be seen in the Agency, the Yellore and Salem Javadis, the North Coimbatore and Kollegal hills, the Nilgiris and the Palnis, many parts of the Hospet and Kudligi taluks of Bellary and many parts of Kurnool district.

Realising the folly of cultivation steep slopes, the Government of Madras took steps to stop the assignment of land exceeding a slope of 1 in 4 some years ago in the Nilgiris and the Palnis. With the drive for extending cultivation during the war however these orders are not observed as closely as they should be. In a province where the total production of manure is sufficient for only 50 per cent of the land under cultivation, the retention of lands of this type under the plough is uneconomic and they should be withdrawn altogether from cultivation and allowed to revert to natural cover.

Soil conservation on slopes unsuited to cultivation.—All measures for soil conservation must aim at preventing runoff from attaining a dangerous velocity and thus achieve soil stabilization. As this process goes on, adequate steps must be taken to clothe the area with natural vegetation and to see that this vegetation is preserved and not exposed to hazards, such as fires. In dealing with any control measures against erosion the essential requirement is to identify the problem, trace the trouble to its source and tackle it from the source. Only by such a study of cause and effect can a complete solution be found. The whole catchment or drainage area bounded by the water sheds is the topographical unit for working purposes. Any soil conservation work must therefore start at the head of such topographical units and worked downwards.

Dealing first with the various works suitable for stabilizing the soil, it must be emphasized that it is impossible to prescribe any one of them by any definite formula. Work can only be done economically by experienced technicians and much money may be wasted by inexpert handling. Conditions vary almost from acre to acre, so that no one prescription would meet any one area.

The simplest forms of soil stabilizers are small wattle work revetments 15–30 feet long held by stout pegs and staggered throughout the danger zones. Where available, rough stones may be formed into small bunds in front of such revetments. Where conditions are suitable shrubs can be used to form natural revetments by cutting and pegging them down with crowns uphill. On steeper slopes where the soil is more unstable rough stone or even *pucca* masonry revetments may be needed. In construction the essential requisite is to excavate the foundations with a slight slope inwards and to build the uphill face vertical and the down hill face with a batter of 3:1 to ensure stability once silt has accumulated above the revetment. Such works can however only hold up silt and assist in increased percolation. They have no storage capacity to hold the runoff water, nor do they provide for its safe disposal by drainage. This is done by contour trenching or channelling. In this work trenches are constructed along the contour (i.e., along the level) or on a slight gradient to interrupt runoff long enough to allow it to sink into the soil, or where it is excessive to provide cross drains to dispose of it with a minimum of damage. In a primitive form it is not new, for we are all familiar with the bunding of fields known in Northern India as *watt bandi* carried out on sloping fields by all good farmers.

In the hilly areas of the dry districts such work should be designed to hold up as much runoff as possible. In America for example the designs hold up 75 per cent. of the rain falling at a rate of 2 inches per hour. The trend of thought in that country where soil conservation has progressed tremendously in the past 10 years is all towards the utilization of the water storage capacity of the soil as a natural reservoir gradually resuscitating the springs long gone dry and so extending the period of flow in the streams and reducing the necessity for heavy expenditure on down stream water storage works the storage capacity of which is being continually reduced by silting.

The remedial measures now adopted all over the world to prevent or reduce surface runoff and soil erosion and increase crop production consist of contour bunding, contour-trenching, gully-plugging, terracing, regulated forestry, controlled grazing, re-vegetation, selective weeding, cover cropping, mixed farming, crop rotation, strip cropping, etc. The first three methods are mechanical and the rest are biological in operation.

Contour ridging consists in making narrow ridges along the contour by ploughing and is chiefly carried out in grass lands with a slope of not more than 25 per cent. The interval between ridges is small, rarely more than 10 feet. It does not completely check runoff, but achieves increased percolation, which has been noted as being responsible for an 80 per cent increase in fodder production. The fact remains however, that such a system concentrates the increased percolation over only a small area, for percolation takes place vertically rather than laterally. It is rapidly being replaced in American practice by the contour furrow system in which a furrow or channel replaces the ridge, the soil excavated being spread evenly over the adjacent ground. It is found that the furrow regenerates quicker than the ridge, and a ridge is always an objection where machinery is being used.

Under Indian conditions these systems could have limited application only. It is possible that they might be used to improve the fodder production on high level downlands such as the Nilgiris or the Palnis.

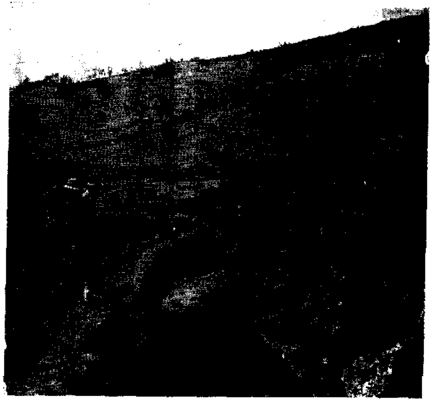


Fig. 46—A TYPICAL EXAMPLE OF SOIL EROSION RESULTING FROM BAD LAND UTILIZATION COMBINED WITH A FAILURE TO TAKE EFFECTIVE CONTROL MEASURES—NANJANAD, THE NILGIRIS

The exposed sub-soil consequent on the loss of top soil is clearly shown. In the foreground is serious gullying. Slope of land near critical limit for cultivation

(*J.R.A. Wilson*)

Fig. 47—SIMILAR TO FIG. 46

Note crest of hill which is village grazing ground. Much overgrazed. Natural grass largely destroyed. Note lack of contour bunds. Serious gullying seen in foreground

Fig. 48—IMPROVED BUT TOTALLY INADEQUATE AND INEFFICIENT CONTROL MEASURES—TAMBATTI, THE NILGIRIS

Note woodland at higher levels protecting the crest. Note also bunds of natural vegetation which are not properly contoured resulting in sheet erosion followed by rill and at lower levels by gullying

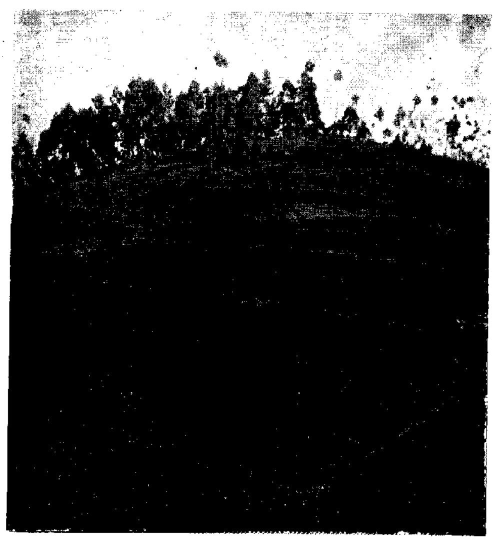


Fig. 49—AREA ADJOINING RIGHT HAND MARGIN OF FIG. 48

Fig. 50—Forest area completely reclaimed by protection against fire and grazing combined with the introduction of Red Sanders (*Pterocarpus santalinus*) which now gives complete cover—Chittoor

(*M. V. Laurie*)

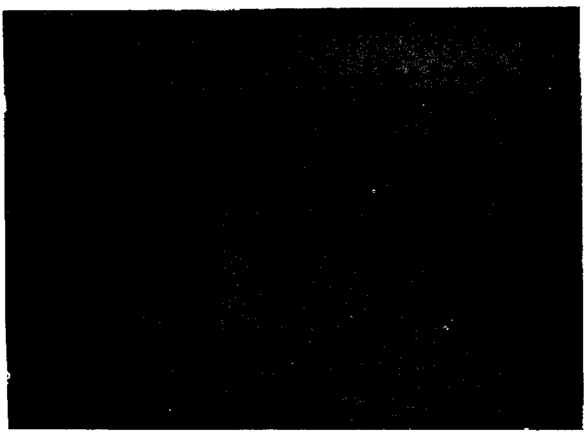


Fig. 51—Arrangement of drains in the rear slope of Kanigiri Reservoir bund to prevent scour

CHAPTER V

CONTOUR BUNDING

Bunding is not a new subject. The dry land cultivator has a knowledge of bunding handed down to him by tradition. Whenever he saw gullies formed or erosion taking place on his field, he was putting up a suitable earthen bund at the lowest point of his field to check erosion. His attempt was purely to prevent soil erosion from his field. The size of his bund was to suit his purse. A large landholder in dry tracts puts up such bunds in more than one place at the lowest points of his fields or across the gullies or *nullas* * formed in his field primarily to prevent erosion and incidentally to store up a little water. But he did not do any systematic or scientific bunding to protect all his lands from the ravages of runoff and erosion. Nor was there any co-operation between him and his neighbour. When the lands in one catchment were owned by several cultivators, some took to bunding and others did not. If only the lands lying along the slope or at the bottom of a catchment were bunded, the runoff from the upper lands which passed through the lower lands before it entered the nearest drain or *nulla* caused damage to the bunds put up in the lower lands. Hence there arose the necessity for providing waste weirs in the bunds put up in the lower lands in the catchments. Such isolated or series of a few isolated bunds provided with waste weirs did not benefit the cultivators commensurately with the expenditure incurred by them for the following reasons:—

(i) Rain water was collected at the lowest point of the fields only.

(ii) There was stagnation at the lowest corner of the bunded fields and the rain water was not well distributed to ensure even percolation over the entire bunded area.

(iii) Much of the rain water was wasted through the waste weirs and with it all the finer particles of soil which are rich in manurial value and plant food were also lost.

(iv) Heavier particles rolling down the field settled nearer the bund and the waste weir.

(v) Due to stagnation of water over some area above the waste weir there was no crop production in that portion.

* Meaning "water course".

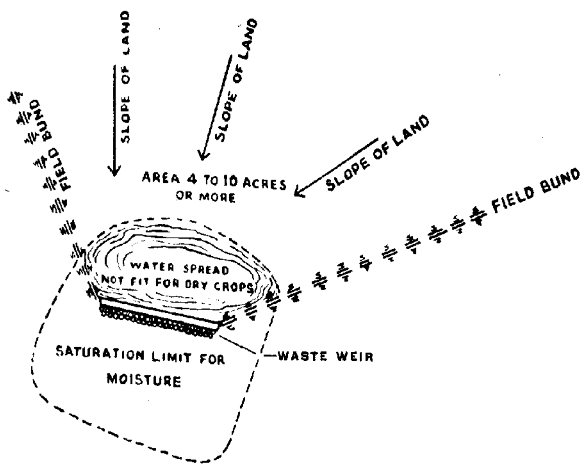


Fig. 52—SKETCH OF CULTIVATOR'S METHOD OF BUNDING

Bunding as resorted to by the cultivator was not in accordance with any correct principle. There was no limit for the area of the land provided with bund. There was no definite rule for the size and shape of the bund or for its location. The cultivator always put the bund along the boundary of his land at the lowest point, of any dimensions he liked with reference only to his finances but without reference to his neighbour's lands. Such bunds are seen all over the Bijapur and Sholapur districts of the Bombay Presidency and in the Ceded districts, the Coimbatore and the Ramnad districts and elsewhere in this Presidency also.

In the Bombay Presidency, more enterprising and rich landlords owning large extents of lands in the order of hundreds of acres have taken to larger bunding schemes known as flooding schemes. Such a scheme chiefly consists of a huge or mass bund resembling an irrigation tank bund of sufficient length thrown across a drain (or *nulla*) and provided with a waste weir (or surplus weir) at the point of the crossing of the bund and the *nulla* course with vents at different levels (or tiers) so that the water spread at the weir crest level may be 50 to 100 acres with reference to the nature, slope, etc., of the catchment thus intercepted by the bund. The object of this scheme is to hold up the first on-rush of the runoff in the drain up to the weir crest level for some days so that the lands coming under the flood influence may be fully saturated with water and get the benefit of the silt. When the runoff ceases, the water level in the

storage is gradually lowered by operating the vents in the weir according to the needs and progress of the cultivation operations. By this scheme, the cultivator gets good benefit and his lands in the tank-bed become rich in soil and produce excellent crops. One such flooding scheme constructed by a rich landlord at a cost of about Rs. 10,000 with the free technical advice and help of the Bunding Section of the Agricultural Department at Nimbergi in Sholapur district benefits about 50 acres of dry land. The nulla bed is fit for wheat cultivation. On the bund there is a thick growth of *neem* and *babul* trees which are now estimated to cost about Rs. 4,000 as they have good timber and fuel value—vide sketch below for design of weir used:

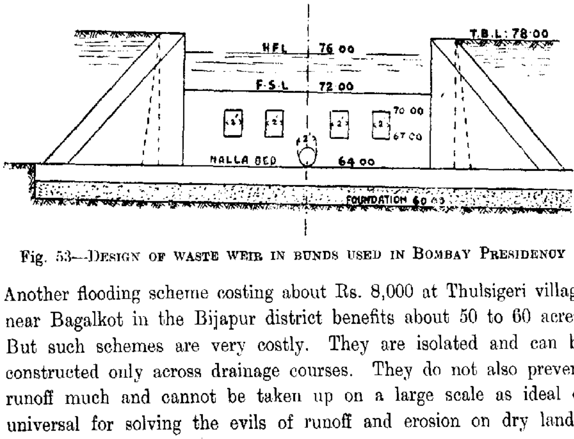


Fig. 53—Design of waste weir in bunds used in Bombay Presidency

Another flooding scheme costing about Rs. 8,000 at Thulsigeri village near Bagalkot in the Bijapur district benefits about 50 to 60 acres. But such schemes are very costly. They are isolated and can be constructed only across drainage courses. They do not also prevent runoff much and cannot be taken up on a large scale as ideal or universal for solving the evils of runoff and erosion on dry lands. They are to be considered only as local treatment.

In the Bombay Presidency, ryots have been doing bunding works on a small scale for the last two decades known as block bunding work comprising of 200 to 500 acres and village development projects comprising of 500 to 1,000 acres under the special guidance of a bunding staff directed by the Director of Agriculture. These schemes consist in putting up contour bunds at intervals of 150 to 200 feet or at contours falling by 3 feet and each contour bund provided with one or two suitable waste weirs. In recent years the ryots have been also getting financial aid to do their village development projects at Rs. 5 per acre from the Kusrow Wadia Trust Fund. Mr. Kusrow Wadia is a great philanthrophist of Bombay. He has had occasion to see the contour bunding work in the United States of America a few years ago and appreciated its efficiency in preventing runoff

and soil erosion and increasing the moisture content of the soil and the crop yield in the bunded area. The interest from a capital of Rs. 7,00,000 set apart for this purpose is distributed to the needy ryots at Rs. 5 per acre for bunding work.

But all these only touch the fringe of the problem. Of the cultivable land in the Bombay Presidency 97 per cent depend entirely on rains. The famine and scarcity districts were getting worse and worse year after year. Hence the necessity arose for launching large-scale bunding in the Province particularly in the year 1943 which was a famine year. Famine was declared in the Bijapur district, and huge famine relief works were started in that district. Simultaneously the Government of Bombay started bunding work under two Land Development Officers as detailed below:—

Land Development Officer, South Circle (for scarcity years)—Bijapur district, Dharwar district, Belgaum district, and Ratnagiri district.

Land Development Officer, North Circle (for ordinary non-scarcity years)—Rest of the province.

Theory of contour bunding.—Contour bunding is constructing or forming small bunds across the slope of the land along the same contour lines or at the same levels. A series of such bunds split the area into small strips. All the rain falling on the land between two contour bunds is retained there itself. Nothing is wasted as runoff. The soil absorbs much of the water and the moisture is retained for a long period. The water entering the soil travels slowly under the soil downwards. This underground movement of water benefits crops on the lands lower down. There is no soil erosion. In areas where the rainfall is small, ill-distributed or precarious, this method of bunding the cultivable lands conserves the available moisture in the soil and is bound to give an assured crop to the cultivator.

In the case of an irrigation tank, the catchment, the waterspread area and the *ayacut* * are three different areas one lying below the other in level. In the case of the contour bunded fields, the field between two adjacent bunds is its own catchment, its own reservoir, and its own *ayacut*. In the case of a storage tank the aim is to concentrate the runoff and store it in the tank for economic use on the *ayacut*. But in the case of contour bunding the object is "dispersion" of rain water under ground for the benefit of the crop. In the case of a tank it will be highly uneconomical to put up a bund of sufficient size to store all the runoff of the catchment and hence the standards for the bund are ordinarily or generally fixed with reference to the quantity proposed to be stored in the tank for the anticipated

* The extent of lands intended to be brought under irrigation from a particular source.

ayacut and provide for a surplus weir of suitable dimensions to dispose of the entire runoff of the catchment on the assumption that the tank will be full when the catchment yields maximum runoff. In the case of contour bunding our aim is to totally prevent runoff and retain it in the soil and incidentally prevent the erosion of the soil also. These broad principles lead us to the theory of contour bunding.

The height of the contour bund depends on the slope of the land, the space between the contour bunds and the maximum intensity of rainfall at any one time. The size of the bund, viz., the slopes, top width and base width depends on the nature of the soil.

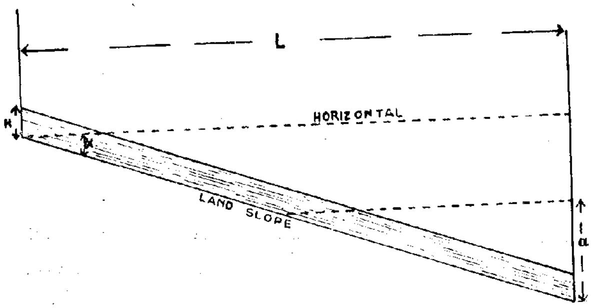


Fig. 54—Sketch showing theory of contour bunding.

Let α be the angle the land makes with the horizontal,

Let the slope of the land be S per cent, i.e., S feet fall for 100 feet horizontal length, then Tan $\alpha = \frac{S}{100}$,

Let H inches be the maximum intensity of rainfall at any one time,

Let L feet be the horizontal spacing of the contour bunds,

Then H inches falling on L feet (sloping length of land is taken same as L) yields $L \times \frac{H}{12}$ cubic feet of water per foot width of bund.

This quantity of water should be prevented from flowing down. Hence the lower contour bund which serves as a check for preventing this runoff should be sufficiently high.

Let the theoretical height of the bund be a feet

$$\text{Then } \frac{L.H.}{12} = \frac{a \times a \cot \alpha}{2} = a \times a \times \frac{100}{S} \times \frac{1}{2}$$

$$= \frac{a^2 \times 100}{S \times 2}$$

or

$$a^2 = \frac{L.H.}{12} \times \frac{2\,S}{100}$$

$$= \frac{L.H.S.}{6 \times 100}$$

In the Ceded districts or in the famine scarcity zones of the Bombay Presidency, the maximum rainfall is generally 5 to 7 inches. It is reasonable to assume the maximum rainfall at any one time as 6 inches for design on the assumption that all the rain water has to be held up and nothing will enter the soil under saturated condition due to previous rainfalls.

$$\text{Then } a^2 = \frac{L \times 6 \times S}{6 \times 100} \times \frac{LS}{100}$$

or

$$a = \sqrt{\frac{LS}{100}}$$

To this theoretical height of bund a free board or safe margin in the height has to be added, to make the bund practically safe from breaching or giving way. It is necessary and sufficient to fix this free board as 1 foot. Then the height of bund can be expressed as—

$$h = a + 1 = \sqrt{\frac{LS}{100}} + 1$$

Let us examine this formula for a few practical cases.

Slope of the land S per cent.	Spacing of bunds L feet.	Drop in level in feet.	Theoretical height of bund a feet.	Practical height or safe height or bund $(a + 1)$ feet.
1	100	1·0	1·0	2·0
	150	1·5	1·2	2·2
	200	2·0	1·4	2·4
	250	2·5	1·6	2·6
	300	3·0	1·7	2·7
	350	3·5	1·9	2·9
	400	4·0	2·0	3·0
2	100	2·0	1·4	2·4
	150	3·0	1·7	2·7
	200	4·0	2·0	3·0
3	100	3·0	1·7	2·7
	150	4·5	2·1	3·1
	200	6·0	2·4	3·4
4	75	3·0	1·7	2·7
	100	4·0	2·0	3·0
	150	6·0	2·4	3·4
	200	8·0	2·8	3·8
5	60	3·0	1·7	2·7
	100	5·0	2·2	3·2
	150	7·5	2·7	3·7
	200	10·0	3·2	4·2

The formula derived above, viz., $a = \sqrt{\frac{LS}{100}}$ can be written in a simple form in terms of drop or difference in the levels of adjacent bunds instead of spacing of bunds L.

Let D ft. be the drop in level between the two bunds—

Then $L = D \cot \alpha$

$$= D \times \frac{100}{S}$$

OR, $a = D \times \frac{100}{S} \times \frac{S}{100}$

$$= D.$$

OR, $a = \sqrt{D}$

Or, practical height $h = \sqrt{D} + 1$

So, for any slope the safe permissible height of bund is—

$$h = \sqrt{D} + 1$$

Drop between contour bunds in feet.	Safe height of bund in feet.	Drop between contour bunds in feet.	Safe height of bund in feet.
1	2·0	6	3·4
2	2·4	7	3·7
3	2·7	8	3·8
4	3·0	9	4·0
5	3·2	10	4·2

In spacing the bunds, the principles to be adopted are—

(*a*) that the effect of the sub-soil water due to the contour bund above, i.e., the seepage zone below the upper contour bund should meet the effect of the surface water held by the contour bund below, i.e., the saturation zone of the lower contour bund (vide sketch below). If not the area between is bound to suffer and the crops there may fail;

(*b*) the spacing should not be too close together making the land too narrow for cultivation;

(*c*) the greater the spacing, the greater the height of the bund and consequently greater the cost; and

(*d*) the closer the bund, the greater the number of bunds which means again greater cost.

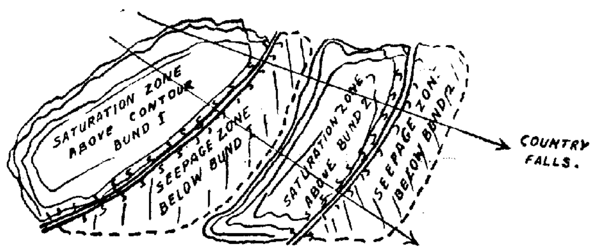


Fig. 55—SKETCH SHOWING SATURATION ZONE AND SEEPAGE ZONE NEAR CONTOUR BUNDS.

The optimum size of the bund and spacing of bund have not been very correctly fixed in the Bombay scheme of bunding. At Nimbergi Experimental Bunding station (21 miles from Sholapur) the Land Development Officer, Northern Circle, has started experiments with different sizes of bunds and varying drops between bunds to study which combination of bund and drop between bunds gives good results in crop yield, etc.

An area of about 2,500 acres is selected at Nimbergi village and Bhandarkawathi village comprising a single catchment and split into eleven equal plots of 200 acres approximately and experiments are conducted as below from 1943 cultivation season:—

Plot numbers.	Method of bunding and cultivation.	Remarks.
1	Cultivators practice of dry farming ..	No bund.
2	Contour cultivation, i.e., ploughing along the contour or across the slope.	Do.
3	Contour cultivation and scientific dry farming.	Do.
4	2 feet bund and 2 feet fall	Waste weirs built in these 6 items.
5	3 ,, 2 ,, ...	
6	3 ,, 3 ,, ...	
7	3 ,, 6 ,, ...	
8	3 ,, 9 ,, ...	
9	2 ,, 3 ,, ...	
10	3 ,, 3 ,, ...	Without waste weir.
11	3 ,, 3 ,, ...	Rigid contour.

REFERENCE :

—,.—,.— For deep soils above 18″ depth.

,, medium soils up to 18″ depth.

--- --- --- ,, light soils up to 9″ depth.

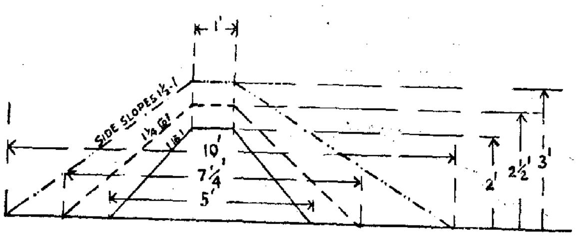


Fig. 56—SIZE OF BUNDS ADOPTED IN THE EXPERIMENTS.

In the large-scale bunding work done in Bijapur district the principles adopted are as follows:—

(i) An entire catchment is taken up for contour bunding.

(ii) The contour bunds are formed at intervals of 3 feet drop.

(iii) The height of bund is 3 feet.

(iv) The section of the bund is as follows:—

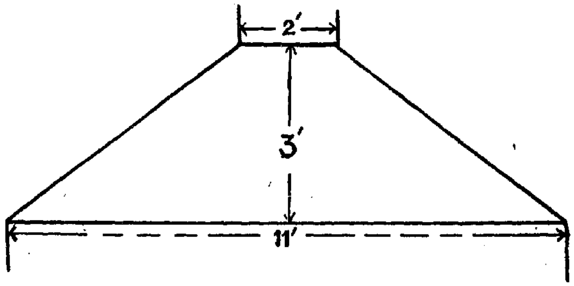


FIG. 57.—SECTION OF CONTOUR BUND.

For a 3 feet drop the spacing of bunds works out as below for different slopes:—

Slope per cent.	Horizontal spacing of bunds in feet.	Slope per cent.	Horizontal spacing of bunds in feet.
1	300	6	50
2	150	7	43
3	100	8	38
4	75	9	33
5	60	10	30

From the foregoing the following standards for contour bunding are recommended:—

(1) The drop between the adjacent bunds should be 3 feet (as per Bombay practice) for lands having 1 per cent slope and more. On lands having less than 1 per cent slope, the bunds should be spaced at intervals of 150 to 200 feet and the section of the bund should be fixed up for each slope.

(2) The theoretical height of bund for a 3 feet drop is—

$\sqrt{3} = 1{\cdot}7$ feet and the safe practical height $1{\cdot}7 + 1 = 2{\cdot}7$ or 3 feet (as per Bombay practice).

(3) Contour bunding should be taken up only in lands whose slope is less than 6 per cent ordinarily. It is even better to limit the slope to 4 per cent.

4

(4) The section of the bunds when they are spaced at 3 feet drop should be as follows:—

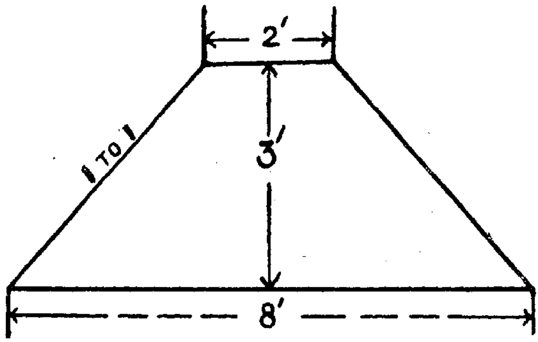


Fig. 58
Type (1)—Light or shallow soil where the soil depth does not exceed 9 inches
N.B.—It is possible to take a little *muram* soil from the burrow pits and coat the bund with *muram* when 1 : 1 slope will be enough.

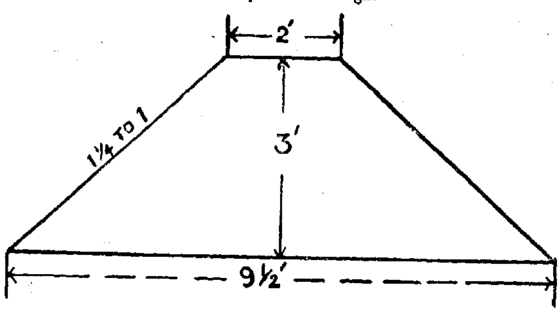


Fig. 59
Type (2)—Medium soil where the depth of soil is from 9 inches to 18 inches

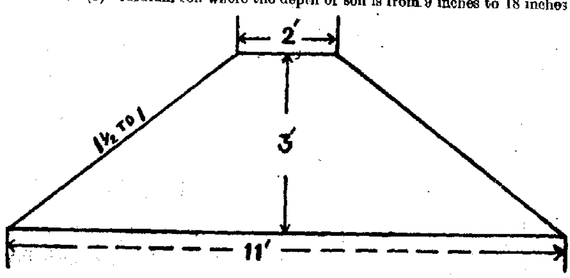


Fig. 60
Type (3)—In deep soil where the soil depth exceeds 18 inches

In the major portions of the lands where the slope is less than 4 per cent only medium and deep soil as in the Bellary and other districts are expected.

Hydraulic gradient—Examination of the above three typical sections for hydraulic gradient.—The maximum depth of water for 6 inches rains at a time is expected to be 1·7 feet ($\sqrt{D} = \sqrt{3}$) for a drop in contour of 3 feet. Hydraulic gradient line of 1 in 4 is adopted for examination. The maximum depth of 1·7 feet will be obtained very rarely once in several years. The ordinary water level in any year will be less than 1·7 feet.

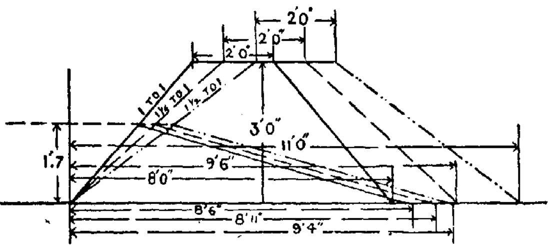


Fig. 61

Type (1) ———————— **Hydraulic Gradient 1 in 4 in all cases**

Type (2)— — — — — — **H.G. Line intersects base: 6" outside toe, 7" inside toe and 1' 8" inside toe**

Type (3). —..—..—..—.. **Dry earth cover on H.G. Line—Nil; 0·5 foot and 1·0 foot respectively**

Sections as per types (2) and (3) are safe. Section as per type (1) is not safe. But it is possible to give a coating of gravel or *muram* on top of slopes. Hard soils are expected below 6 inches or 9 inches in places where this type is proposed to be adopted and this will afford obstruction to flow of seepage through the bund and keep the H.G. line steeper than 1 : 4. Hence this section is allowed to stand as it is.

Bunds of type (3) when spaced at 200 feet intervals involve—

(1) 217·8 or 220 feet length of bund per acre of land bunded.

(2) 4,207 cubic feet of say $4\frac{1}{2}$ units of earthwork per acre bunded.

(3) $4\frac{1}{2}$ units of earthwork cost approximately Rs. 18 at Rs. 4 per unit per acre bunded.

(4) $5\frac{1}{2}$ per cent approximately of land is occupied by the bund.

N.B.—In type (2) bunds, the area of land occupied by the bund is $4\frac{3}{4}$ per cent. In type (1) bund, it is 4 per cent.

Roughly with all kinds of bund sections and the bund spacing, it is reasonable to assume the area of land occupied by the bunds at 5 per cent.

Though the area occupied by the bund appears to be a waste of land really it is not so. The cultivator can easily grow castor, safflower, etc., which thrive very well in the contour bunds erected

in the Bijapur district in 1943. The ryot is sure to get at least double the normal yield of crops and straw from the bunded land in normal years against the 5 per cent of land sacrificed by him for the bund and at least 50 per cent more in scarcity and famine years.

Large-scale bunding work done in the Bombay Presidency in 1943.—The Land Development Officer, Southern Circle, Bijapur, started bunding work in March 1943. The total area contour bunded in that year was about 95,000 acres and it is learnt that up to date more than 10,000 acres have been bunded at a cost of about Rs. 12,00,000 at Rs. 12 per acre on an average. The bunding work done in 1943 is called " Large-scale experimental bunding " and it is understood that it is not proposed to recover any portion of the expenditure from the ryots for this work as it was " experimental " and done in a famine year. The work was done at 27 centres or schemes comprising of several villages. The crops grown in the locality are generally cotton and *cholam* (or *jowar*). The crops in the bunded fields were found to be definitely superior to those in the unbunded areas. The yields of grain and fodder on the bunded lands is estimated at 75 per cent more than on the unbunded lands, and where scientific dry farming methods were adopted in the bunded area, the yield was estimated to be 150 per cent more than that of the yield from an unbunded land cultivated according to ryots' practice. In the year 1943, about 8,000 acres were cultivated by the ryots as per scientific dry farming methods in the bunded area.

The magnitude of the contour bunding work proposed to be taken up in 1944–45 in the Bombay Presidency can be appreciated from the following figures:—

(1) *Area proposed for bunding in the southern circle*—

	LAKH OF ACRES.
North Bijapur	1
South Bijapur	1
Karnatic-Dharwar	1
Total ..	3

(2) *Budget demand for bunding work in the southern circle for* 1944–45—

	RUPEES IN LAKHS.
Bunding 3 lakhs of acres	30
Terracing in Konkan (Ratnagiri district).	12
Establishment, etc., charges	8
Total ..	50
(3) *Budget demand for northern circle*	20
Total for the Province ..	70

Contour bunding at Hagari.—The agricultural farm land at Hagari is almost level having a slope of less than 1 per cent. The land is worked up and levelled for the last several years for conducting experiments. Dry farming researches were made in this farm for 9 years from 1934–35 to 1942–43. Some of the experiments were conducted on bunded plots. The bunds were 7 inches high and made by bund-formers. The results of experiments show that these bunded plots retain more moisture and yield better crops. Being small, the bunds deteriorated every season and they had to be re-formed every year. Contour bunding was not done in this farm till 1943. In 1943 about 50 acres of private lands were taken up for contour bunding by the Agricultural Farm. Twenty-nine acres were bunded all round (called peripherical bunding) with contour bunds and waste weirs on contour bunds. In the remaining 21 acres bunds were not fully completed. The yield of grain and straw from the 29 acres of contour bunded lands was higher than the yield from the adjacent unbunded lands. This should be ascribed to the retention of more moisture in the bunded lands than in the unbunded lands, other factors such as nature of crop, quality of seed, seed-rate, method of cultivation, etc., remaining constant.

Whether waste weirs are necessary in the contour bunds.—Before large-scale bunding was commenced in the Bombay Presidency in 1943, the ryots were accustomed to bund up their fields in the lowest place. The catchment above the bund was anything varying from a few acres to many acres. There was no compartmentation of the catchment above the bund. Subsequently bunding of areas up to 1,000 acres was done by the ryots with the technical assistance of the Agricultural Department Officers with or without *takkavi* loans or grants from the Kusrow Wadia Fund. In all these cases, the area tackled was only a portion of the catchment of a drain or *nulla*, lying along the slope of the catchment either in the middle of the slope or at its bottom. Hence the area taken up for bunding had to receive the runoff from the portion of the catchment lying higher up and divert it lower down into the valley. Waste weirs were therefore provided in the contour bunds. In cases where bunds were formed along the contours the highest or first contour bund of the series is purely of the nature of a tank bund which should be sufficiently strong to withstand the impact of the runoff from the higher catchments. It should also provide for a surplus weir. The surplus water has to go through all the series of the bunds lower down through waste weirs provided in each contour bund till it enters the drain in the valley below. Waste weirs in the contour bunds will be unnecessary if the entire catchment of a drain is tackled instead of dealing with it piece-meal. This is the main principle adopted in the large-scale bunding

now initiated in the Bombay Presidency. Under this scheme the entire catchment is split up into small compartments by the contour bunds starting from the very ridge and proceeding downwards along the slope till the valley line is met with. Each compartment therefore deals only with the rain it receives and has nothing to do with its neighbouring compartment higher up. Waste weirs are not therefore necessary in this case and not a single waste weir has been built in the one lakh of acres bunded in Bombay during 1943. The provision of waste weirs is also against the principle of water and soil conservation. Waste weirs facilitate unchecked runoff and valuable water and silt are washed out leaving the soil barren. The heavier particles of sand and stones are deposited in front of the weir while the fine silt which is rich in manurial value is wasted into the nulla. It is also financially a waste of money to put up these weirs in a contour bunding scheme. From an agricultural point of view also waste weirs are unnecessary [*Jenkins*, 1944]. Contour bunds will retain small rains received early in the months of May and June on the field itself and facilitate the raising of early crops. In the Bellary district and other parts of the Ceded districts, the maximum rains are generally received in the month of September to the extent of about 5 inches and it is in this month that contour bunded fields without waste weirs may to some extent be affected. Even this difficulty may be safely overcome if agricultural operations are postponed to the latter half of September. The cultivator will certainly adjust his field operations to suit the rains. In any case the failure of crops due to too much of moisture in the bunded fields will perhaps be once in 5 or 6 years whereas they will give very good crops in the remaining years.

Execution of contour bunds.—Before a contour bunding scheme is put to execution, it is necessary to know the details of the catchment such as its entire area, ridges, and valleys, how the country undulates, the depth of soil in the catchment at different levels, whether the soil is hard, gravelly or loose, etc.

Before large-scale bunding was taken up in Bombay only small schemes which did not ordinarily exceed 1,000 acres were worked. So the country was carefully surveyed, and cross sections taken at intervals of 100 feet or 50 feet. Contour lines were then marked on a plan by interpolation of contours at vertical intervals of 2 or 3 feet and approval got for the compartmentation. The contour bunds were finally marked out on the field for execution. This method is termed contour bunding by the method of *interpolated contour* or *derived contour*. When mass scale contour bunding was done in the Bijapur district in 1943, it was not possible to adopt this orthodox method and so the contour lines were fixed on the field straightaway. This

method is called *direct contouring*. By this method the contour plans are not prepared first and then the bunds marked on the field. But the bunds are marked on the field first and constructed and then the plans showing these bunds are prepared by marking them on the village plans by the method of pacing the distance of the bunds from the survey lines. This is a simpler method and saves time and labour for double levelling. In a work of this kind it is not necessary to read the levels to second decimal places and errors up to $\frac{1}{3}$ or $\frac{1}{2}$ a foot in the contour lines will not be harmful and can be tolerated. This method of *direct contouring* is described below:—

The area proposed to be contour bunded is reconnoitred by a surveyor. He fixes up the ridge lines and valleys from his reconnaissance, or from a topographical map, if available, or from local enquiry and from the land marks in the locality such as roads, drains, etc. Then he fixes along the roads bench marks at intervals of 1 furlong all around the catchment dealt with. Next he marks the contour lines at 3 feet intervals (or drops) with his levelling instrument by guiding the staff man by " trial-and-error " method by asking him to move forward and backward along the slope of the country till he holds the staff at the correct level required. Then a peg is driven or a few stones are piled or a small earth mound is put up there. At one setting the surveyor can command the fields for about half a furlong easily. By going along one contour line ' A ' at 97·0 the surveyor can fix up the contour lines " a 1 " and " a 2 " right up and lower down, viz., at 100·00 and 94·0 contours by keeping one staff man for each contour line in a country sloping gently. In fact his work will be facilitated if he can have two staves for each contour line.

a 1	**100·0 contour.**	**b 1**	**91·0 contour.**
A	**97·0 "**	**B**	**88·0 "**
a 2 .. .	**94·0 "**	**b 2**	**85·0 "**

Having fixed several points along each contour line, the line is marked out by a wooden pole or lockspitted. The base width of the contour bund is marked on the field for execution by what is known as a ' marker '. A marker is a simple woodden instrument in the form of a ' T '. In one arm of the ' T ' there are four holes t 1, t, T 1 and T and a peg 6 inches long is permanently fixed at G, the centre point; t and t 1 are 4 feet apart from the centre and T and T 1 are $5\frac{1}{2}$ feet apart from the centre. If the base width of the contour bund is 11 feet in black cotton soil then two pegs are driven through the holes T and T 1 and the marker is drawn by the other arm or the handle moving the peg at G along the centre line. Then the pegs at T and T 1 scratch the toe lines of the bund on the ground. These toe

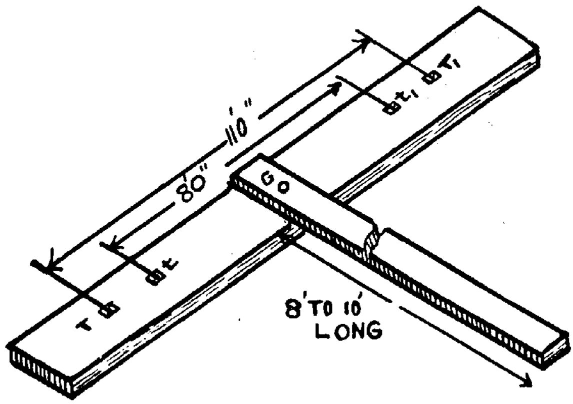


FIG. 62.—MARKER.

lines are made firm or *pucca* by one coolie for each toe line with a pick-axe or preferably by a mammooty. If the base width of the bund is to be 8 feet in hard soils, then the pegs are put in the holes t and t 1 and the operations carried out. Then the burrow pits are marked out. For black cotton soil bunds whose dimensions are: base width 11 feet, top width 2 feet, height 3 feet and slopes $1\frac{1}{2}$ to 1, the quantity of earthwork per running foot of the bund is $19\frac{1}{2}$ cubic feet and so the cross-section of the pit at right angles to the bund is $19\frac{1}{2}$ square feet—vide sketch below.

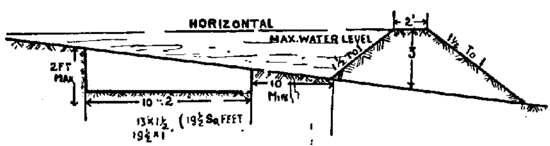


FIG. 63.—SKETCH OF CONTOUR BUND WITH BURROW PIT.

Note.—The burrow pits should all be marked always on the upstream side of the bund to be formed and never on the rear side (or downstream side). By doing so the pit will get automatically filled in one or two seasons by the rain water flowing along the slope if the soil is loose as in the case of black cotton soil and in 4 or 5 years in other hard soils.

The burrow pits should be sufficiently away, say 10 feet from the inner toe of the bund to prevent the inner slope of the bund slipping into the burrow pit. This space of 10 feet can also be ploughed and cultivated as this portion will get the maximum benefit on account of its proximity to the contour bund. If this space is 2 or 3 feet it

becomes unfit for cultivation on account of its narrowness. This is waste of land and that too the best portion of the land.

During execution the slopes should be properly formed and the top properly levelled. As these are small bunds special care should be taken to form them in accordance with the specifications and exactly to the prescribed standards, lest they should deteriorate very soon. We cannot allow any bund to be weak, as failure of any bund will result in failure of the chain of bunds lower down. The strength of a chain is that of the weakest link. Similarly the efficiency of the contour bund scheme depends on the strength of the individual contour bund. During execution this should be borne in mind.

Where the country is undulating badly, the contour line will be zig-zag. If the bund is laid along this zig-zag contour line *rigidly*, there will be too many bends and this will interfere with the cultivation operations. Hence this rigid contouring requires some straightening here and there so that the bunds may be straight for at least 100 feet to facilitate ploughing. Such straightening of curves should be done before the base width of the bund is marked on ground and earth-work is started.

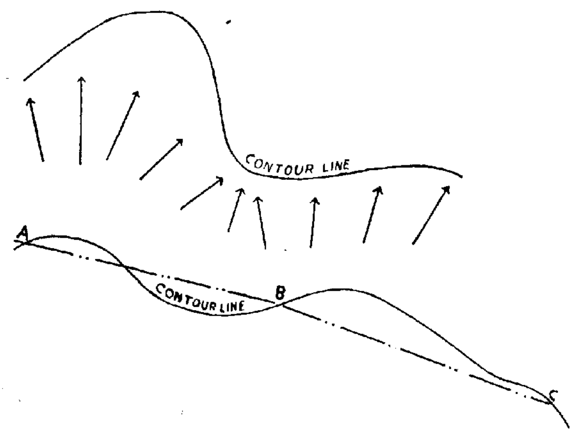


FIG. 64.—STRAIGHTENING OF CURVES IN CONTOUR LINES WHEN CONSTRUCTING CONTOUR BUNDS.

AB and BC are straight lines which follow the contour line approximately. In straightening, it is reasonable to deviate even up to 3 to 6 inches in the contour level to facilitate agricultural operations.

In practice, it is necessary to see that the contour bunds do not traverse across each holding in such a way as to throw small portions of it out of cultivation. It is necessary to put the bunds along the

field boundaries themselves if they are within 10 or 12 feet of the contour lines.

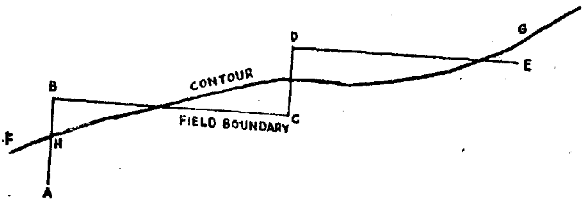


FIG. 65.—CONSTRUCTING CONTOUR BUNDS ALONG FIELD BOUNDARY.

A B C D E is field boundary
F G contour line.
The contour bund to be laid along F H B C D E instead of taking away corners of fields by following the contour line rigidly.

Mechanical methods of control of erosion—Bund-former.—Bunding of fields is done by means of an implement called the bund-former designed by the Madras Agricultural Department. It is a very simple labour-saving implement for forming bunds or ridges and can be used also for forming bunds for irrigation in garden lands. In dry lands, it can be used for forming bunds across slopes to prevent erosion after heavy rains and for conserving moisture. Rain water is held well in the compartments made by the bund-former. The bund-former which forms bunds of about 7 inches height can cover about ten acres a day. The bunds which are formed before the rainy season get erased during the sowings. Therefore, bunding by the bund-former is an annual operation and in dry lands it is being advocated as part of the preparatory cultivation like working the ' Guntaka ' or blade harrow. This operation in itself is sufficient to arrest runoff in gently sloping lands.

Basin lister.—A simple implement for forming scoops or basins in the field is the " Basin Lister." It is essentially a furrower fitted with an eccentric cam arrangement. The furrower which cuts a furrow in the land is lifted at regular intervals and dropped. It does not cut the soil where it is lifted resulting in a series of cross bunds to the furrow. These have the appearance of basins and the implement is known as basin lister. It works about 2 to 3 acres a day in heavy soils. In sloping fields the velocity of the runoff waters is minimized by throwing the land into pockets and erosion is thereby reduced. From quantitative measurements it was shown how scooping was effective in reducing erosion losses to less than half those occurring in the control plots. In combination with raising of embankments, this should prove very effective in the control of erosion.

Area for a unit scheme for bunding.—A compact manageable unit should comprise of 5,000 acres for a bunding scheme. One overseer or surveyor with one levelling instrument can mark contour bunds for about 1 to 1½ miles per day. The average can be taken as 1¼ miles safely. This means about 30 acres roughly per day. In a month of 24 working days about 24 × 30 or 720 acres or roughly one square mile can be contoured and marked on field. Including execution work such as marking pits, forming bunds, measuring, preparing bills, etc., he can safely do only 300 acres per month. Contour bunds alone for 300 acres will cost about 300 × 4½ units or 1,350 units of earthwork [4½ units of earthwork per acre as per type (3) section at 200 feet spacings] or at Rs. 4 per unit, Rs. 5,400. If a portion of this area comes under trenching in the uncultivable lands for preventing soil erosion and runoff, and afforestation work, the average cost per acre may go up to even Rs. 25 per acre. In this case the cost of work may go up to even Rs. 7,500 for 300 acres and this is the safe amount of work that can be entrusted to an overseer or supervisor per month. Hence 5,000 acres will be completed in 5,000/300 = 16⅔ overseer months or 4 overseers can do this work in a little over 4 months. Allowing for dearth of coolies, epidemics and other unforeseen difficulties, one unit of 5,000 acres can be completed in all respects including final bills, settling accounts, etc., in about 6 months from March to August and in the other months they have to prepare plans showing the bunds on village plans to form permanent records, etc.

Cost and upkeep of the bund.—In the Bombay Presidency, a portion of the cost of the bunds is proposed to be recovered from the ryots. The approximate cost of bunding is worked out as Rs. 18 per acre including cost of construction, other overhead and interest charges. Half the cost of this, viz., Rs. 9 is proposed to be recovered from the ryot in 14 years as below:—

First two years ..	**No recovery.**
Next twelve years.	**At Re. 0–12–0 per acre per annum uniformly.**

The recovery will not be made in any bad or famine year and the recovery will be postponed by this duration. According to the Land Improvement Scheme Act of the Bombay Presidency, the ryots have to maintain the bund always up to prescribed standards and if they allow the bunds to fall into disrepair, the repairs will be carried out by the Government and the cost recovered from the cultivators.

How bunding schemes affect other irrigation interests.—By contour bunding and trenching the entire catchment of a valley or drain, runoff is fully arrested. All the rain falling on the catchment is utilized by the soil for underground seepage, plant consumption (or transpiration) and evaporation. If the catchment of irrigation

tanks are taken up for bunding, the storage of the tank will be considerably affected and the *ayacut* under the tank is bound to suffer. In the case of very small tanks having *ayacuts* less than 30 or 40 acres perhaps the tank itself may have to be abandoned ultimately. But the position of bigger tanks is different. It may not be so easy to abandon them. So the extent of contour bunding of such a catchment should be dealt with judiciously on its merits.

Again the catchment of new projects under execution or projects under contemplation deserves close scrutiny and investigation before a decision is taken on the scope of contour bunding. Generally, there are a larger number of irrigation tanks in the red soil (or inferior soil) tracts as in the Anantapur district and fewer irrigation tanks in the black cotton (or superior soil) tracts as in the Bellary district. So it is recommended that when contour-bunding schemes are proposed for execution black cotton soil tracts are given first preference to the red soil tracts in the Ceded Districts.

Preparation of bunding records.—When the fields are contour bunded, the general features of the country are altered. The survey number and holdings are split up by these bunds. It is necessary to see that these bunds put up by the Government are not obliterated by the ryots and that they are properly maintained by them. For facilitating all these, it is necessary to have these bunds marked on village plans and field measurement books, and kept as a permanent record for reference and guidance.

Tools and plant for forming contour bunds.—In the mass scale bunding in the Bombay Presidency, the entire work was done in 1943 with pickaxes and mammootties and it is proposed to do the rest of the work in future years also with these tools only. It is therefore not necessary to go in for any elaborate machines like the bund-formers, tractors, bull dozers, etc., for similar work proposed for this Province where manual labour is available in plenty.

Benefits of bunding schemes.—The extent to which any cultural method is effective in the conservation of moisture can best be judged only by a study of the moisture condition before and after periods of heavy rainfall of the fields which received the cultural operation. Data have been collected on this aspect of the problem at Hagari over a series of years. The following are some typical figures which go to show quantitatively the amount of rain water that is absorbed by a bunded field and an unbunded field during periods of rainfall. From the difference in the moisture content of the fields before and after rains, the amount of rain water that gets converted into soil moisture is determined.

Dates.	Rainfall between the dates.	Layer of soil 0–3 feet.	Moisture per cent unbunded.	Moisture per cent bunded.
	INCHES.	FEET.		
16th August 1938 ..	6·15	0–3	15·3	15·4
1st September 1938 ..		„	22·4	24·8
Increase in moisture—				
In per cent	..	..	7·1	9·4
or in inches	..	..	3·41	4·51
14th September 1939 ..	10·39	0–3	17·6	15·8
6th November 1939 ..		„	24·8	26·0
Increase in moisture—				
In per cent	..	..	7·2	10·2
or in inches	..	..	3·46	4·90
30th August 1940 ..	6·49	0–3	20·1	20·3
15th October 1940 ..		„	23·8	28·7
Increase in moisture—				
In per cent	..	..	3·7	8·4
or in inches	..	..	1·78	4·08

The conservation of moisture effected by bunding is shown in the above tables. During periods of heavy rainfall in the three seasons 1938–39 to 1940–41, the absorption by the bunded field was higher than that by the unbunded field.

Rainfall.	Rain water absorbed by unbunded fields.	Rain water absorbed by bunded fields.
INCHES.	INCHES.	INCHES.
6·15	3·41	4·51
10·39	3·46	4·90
6·49	1·78	4·08

The saving in moisture due to bunding would be better appreciated if it is realized that the net amount of water utilized by the annual crops, cotton and *cholam*, and converted into dry matter is only about three inches. Every inch of soil water conserved is therefore a substantial gain which will go a long way towards the successful production of crops in dry areas.

Contour-bunding schemes aim directly at putting the entire rainfall on the bunded lands, preventing runoff altogether, stopping erosion of soil, and increasing soil moisture in quantity and duration and thus help good crop production. But there are many other indirect benefits accruing from the bunding schemes and they are described below:—

The lower strips of contour-bunded area, i.e., the strips of land lying on the margins of the *nullas* or drains will be getting the benefit

of subsoil moisture in greater quantity and for longer period than those in the upper strips of the catchment. These lower strips are therefore fit for growing more than one crop or an aquatic or semi-aquatic crop like paddy, wheat, *ragi* or maize.

Contour bunding prevents surface runoff and increases subsoil water which travels downwards slowly. This phenomenon raises the water table in the catchment and consequently copious springs are developed and water level in the wells in the locality rises higher and higher. It is learnt that the water levels in the wells in the contour-bunded area of the Bijapur district of the Bombay Presidency have shown a marked rise in level. Increase in springs and rise in water level in the wells will certainly help the cultivator to raise garden crops on a more extensive scale with less expenditure on baling charges. Thus instead of tackling only one or two acres of garden crop from a well with its water level about 30 feet below ground level and with a pair of bulls, the cultivator can deal with 4 or 5 acres with the same pair of bulls if the water level in the well is 10 feet below ground level.

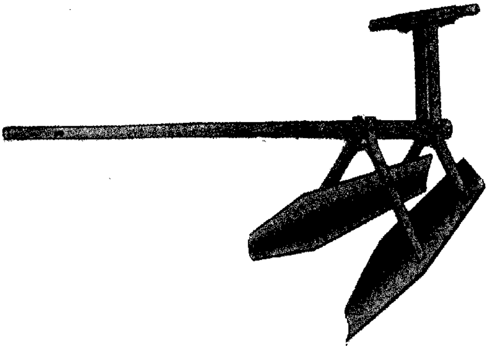


FIG. 66—BUND-FORMER

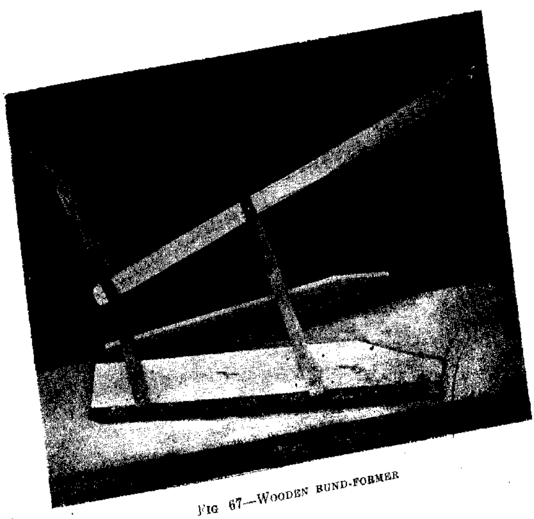


FIG 67—WOODEN BUND-FORMER

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FIG. 68—BUNDED COMPARTMENTS FORMED BY THE BUND-FORMER HOLDING WATER AFTER A FOUR-INCH RAIN

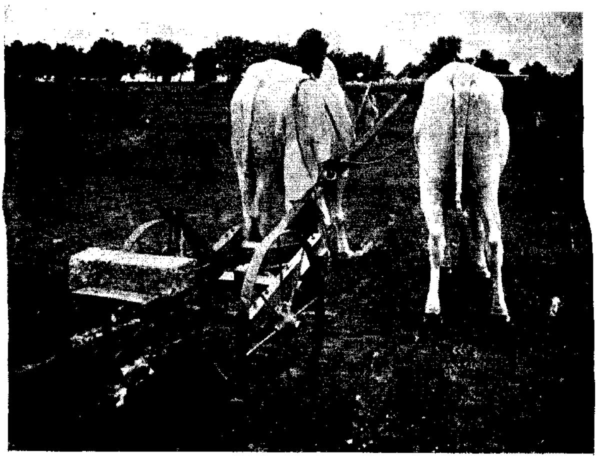

FIG. 69—BASIN LISTER: SINGLE FURROWER

FIG. 70—BASIN LISTER: DOUBLE FURROWER

FIG. 71—BASINS FORMED BY THE BASIN LISTER

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FIG. 72—BASINS HOLDING WATER

FIG. 73—BASINS FORMED BY THE BASIN LISTER HOLDING WATER AFTER A RAIN

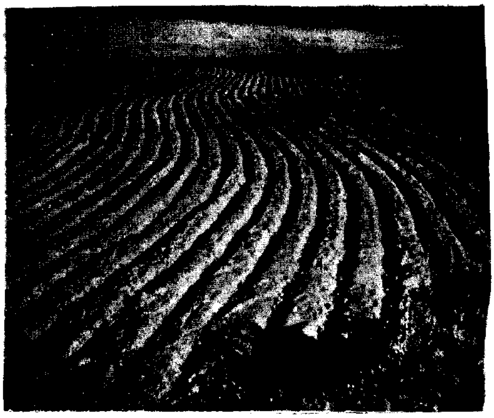


FIG. 74—OKLAHOMA, U.S.A. CONTOUR PLOUGHED FIELD WHICH HAD ONE LEVELLING OF HARROW IN PREPARATION FOR PLANTING COTTON

(Taken from *The Rape of the Earth* by *G. V. Jacks* and *R. O. Whyte*)

FIG. 75—TERRACING IN A FARM IN SOUTH CAROLINA, U.S.A.

Width of terrace 12 feet and height 18 inches

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

FIG. 76—JAVA: TERRACING AND PREPARATION OF LAND PRIOR TO PLANTING COFFEE

(Taken from *The Rape of the Earth* by *G. V. Jacks* and *R. O. Whyte*)

CHAPTER VI

CONTOUR TRENCHING AND AFFORESTATION

THE CATCHMENT of a stream can broadly be classified into three distinct sections in the Deccan tract: the top portion, the middle portion and the bottom portion.

The top portion of the catchment is generally hilly. The slopes are steep and in excess of 10 per cent. The soil is not more than 3 to 4 inches deep. The area is barren, rugged and undulating. This portion is robbed of all its surface soil by nature. Trees are rare and only small jungle growth or shrubs are to be seen here and there. Even grass is a rarity. This area does not ordinarily receive the attention of the local people on account of its barrenness and remoteness from villages.

The condition of the next or the middle section is not so bad. The slopes are less steep and less than 10 per cent. The undulations vary according to locality. Rain has not played so much havoc in denuding the soil. The depth of soil is more and extends up to one or two feet. The land is fit for cultivation. In the shallow soils where the depth is less than nine inches *cumbu*, groundnut and inferior millets can be raised. In places where the soil is more than 9 inches, *cholam*, pulses, etc., can be grown.

In the third section, the soil is deep, i.e., more than 18 inches and sometimes extending to 15 or 20 feet also. The lands slope gently, the slope varying from 0·25 to 5 per cent. The soil is best fitted for cultivation of dry crops such as *cholam*, cotton, wheat, pulses, etc.

In the previous chapter it was stated that any scheme of contour bunding should deal with the entire catchment of a drain or *nulla* to make the scheme cent per cent efficient in controlling runoff and soil erosion, and increasing the amount of subsoil moisture and the duration for which it is held, so as to ensure good crops. But the top portion of the catchment comprising of hills, forests and waste lands and depleted of soil, is uncultivable. No useful purpose will be served by putting up contour bunds in this area. But it is

necessary to control the surface runoff in this portion so that the contour bunds put up in the lower sections of the catchment may stand protected. Such areas are contour trenched and afforested in the Bombay Presidency in the large-scale bunding schemes. About 30,000 acres of uncultivable lands have been dealt with in the Southern Circle of the Bombay Presidency in 1943 in contour trenching and growing forest plants.

Principles of contour trenching.—Contour trenching is excavating trenches along a uniform level or at a particular contour across the slope of the uncultivable waste in the top portion of a catchment and forming bunds at the trenches primarily to protect the contour bunds lower down from the runoff of the upper portions of the catchment. By this method rain water is held up in the slopes for a long time and growth of natural vegetation is accelerated in the slopes. The rain water percolates through the soil slowly and travels down and benefits the better type of lands in the middle and lower sections. The typical section of a trench as excavated in the Bijapur district is as given below:—

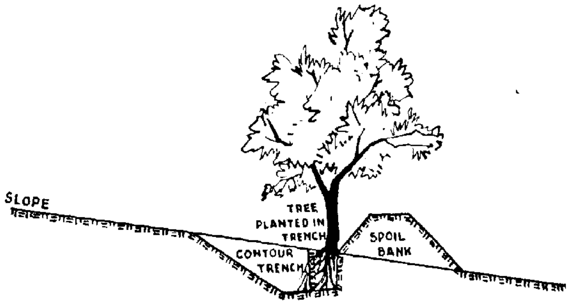


FIG. 77.—TYPICAL SECTION OF A CONTOUR TRENCH AS EXCAVATED IN THE BIJAPUR DISTRICT.

Plants are grown at the inner toe of the bund as shown in the sketch at intervals of 4 or 5 feet.

Contour trenching in its modern form is however most effective. It has been experimented within India for a considerable number of years in the Punjab and the United Provinces with success. In one case from the Punjab this work has reduced maximum runoff from 900 gallons per acre to 50 gallons per acre when combined with natural re-vegetation. Trenches are not more than 50 feet long and are staggered throughout the area dealt with. In cross section they rarely exceed 1 foot × 1 foot, the object being merely to fix sufficient

moisture in the soil to enable the berms to be re-vegetated. Trenches must run perfectly level to use their capacity to the best advantage. As such a system cannot completely check runoff it is necessary also to take steps to control gullies by constructing check dams or bunds of suitable type to reduce velocity and also hold up silt by one or more of the various designs given in Chapter XII.

In America where considerable experience has been gained on a large scale in such work in Civilian Conservation Corps camps in the arid areas of Utah, more elaborate contour trench systems have been built and tested. The general system consists of continuous trenches running absolutely level with interruptions or equalisers 20–40 feet apart forming small basins which hold up runoff. The top of the equalisers is 4–5 inches below the berm of the trench, thus allowing surplus water to spread along the trench. The design of the trenches varies with the slope and depth of soil avilable and three main types are distinguished:—

Standard trench.—(For slopes from 20–45 per cent.) Here, trenches are located with a horizontal interval of 25 feet for 20 per cent slopes to 30 feet for 45 per cent slopes equivalent to vertical intervals of 5–13·5 feet respectively. Cut and fill slopes do not exceed $1\frac{1}{2}:1$. Base of trench and top of berm each 1 foot in width.

Sub-standard trench.—(For slopes from 50–65 per cent with soil over 1 foot depth.) Trenches are located with a horizontal interval of 25 feet for 50 per cent to 30 feet for 65 per cent slopes equivalent to vertical intervals of 12.5–19.5 feet. Cut and fill slopes are 1:1 and $1\frac{1}{4}:1$ respectively. Base of trench 1 foot in width. Top of berm $\frac{1}{2}$ foot in width.

Sub-standard trench.—(For slopes from 50–65 per cent with soil shallow soil.) Trenches are located with a horizontal interval of 12 feet for 50 per cent to 16 feet for 65 per cent slopes equivalent to vertical intervals of 6–10.4 feet respectively. Base of trench and top of berm each $\frac{1}{2}$ foot in width. This type of system with its smaller trenches located closer together will hold 50 per cent of a 2 inches precipitation lasting one hour, and while it is not up to standard, it will hold up all except abnormally heavy storms. It has been tested in the Jaijon *cho* of Hoshiarpur district in the Punjab with spectacular success. It is however expensive and calls for the employment of a large labour force.

The American types described above can again be altered slightly with advantage by converting them into graded contour trenches. In this system trenches can be further apart thus reducing costs, but it must be remembered that this also means a reduction in water

holding capacity and that in abnormal rains the runoff will be much more than what the trenches can carry. Attention is given therefore to providing for the disposal of this surplus with the minimum damage by giving a slight fall towards an outlet into natural streams. The trenches are limited in length to about 1,500 feet. Starting from the end furthest from the outlet the trenches run level for 300–400 feet, then on a gradient increasing from 1 in 500 to 1 in 300 at the outlet. The increase in gradient is designed to dispose of surplus water from the lower level before that from higher levels has time to accumulate behind it. The bunds or equalisers in the trenches are left closer at about 10–15 feet apart. The trenches are located as below according to slope.

Steep slope over 4 : 1 ..	Horizontal interval	0 feet.
Medium slopes 10 : 1—4 : 1.	Do.	20 feet—45 feet.
Gentle slopes 20 : 1—10 : 1.	Do.	45 feet—65 feet.

Having achieved soil stabilization by one or more of the works described above, immediate steps must also be taken to see that the area is reclothed with natural vegetation as quickly as possible and this is especially the case where excavated soil is lying exposed to the rain. We have already seen that denudation was largely the result of fires and overgrazing. Fire protection will be achieved by a system of fire lines. Regulation of grazing will be dealt with in detail below but it must be stated here that under proper land management steep slopes should be closed to all grazing. Where grass is available it should be removed by cutting and used either for stall-feeding or stored as hay against the hot weather. These measures will in themselves usually result in very great improvement to ground cover with little expenditure. They must however be supplemented by artificial introduction of cover plants wherever the soil has been exposed. Usually the first step is to introduce a quick growing soil binding grass such as *Cynodon dactylon* (*hariali*), *Amphilophis pertusa or Pennisetum clandestinum* (*kikiyu*) the latter only at altitudes of 4,000 feet and above in Madras. Once exposed areas have been covered by grass, the next step should be taken to introduce tree growth wherever it is necessary to supplement existing growth. This is not a simple operation in arid areas and requires careful technical supervision, if any success is to be obtained. The work consists of direct sowing of seed in the pockets of silt collected by the wattle or rough stone bunds or by the dry stone or masonry revetments or along prepared strips on the trench berms. Mere broadcasting of seed is waste of money. With good technical supervision the tree crop will grow rapidly and within 10 years should have improved the area appreciably. As natural cover improves,

the runoff decreases and the objective is gradually realized. The tree species to be sown should be drought resisting and hardy and the species found growing locally serve as a good guide. Experience has shown the following to be suitable for low elevations in Madras:—

Acacia planifrons,	*Zizyphus jujuba,*
„ *ferruginea,*	*Pterocarpus santalinus,*
„ *lencophloea,*	*Pterocarpus marsupium,*
„ *sundra,*	*Cassia siamea,*
Albizzia lebbek,	*Hardwickia binata* (*anjan* or *acha* in Tamil),
Prosopis juliflora,	Tamarind and
Chloraxylon swietenia,	Cashewnut.
Azadirachta indica,	

The contour trenches and bunds put up nearby the trenches in the Bijapur district in 1943 are not uniform. No definite standards have been followed. The trenches were cut at 70 feet intervals to start with. Now they are being cut at 150 feet intervals. They are generally 3 feet wide and 1 foot deep. But the soil removed in digging such trenches is not sufficient to make up a standard bund. In some places borrow pits have been put and the bunds have been made up to 3 feet in height. In some other places they are even 2 feet high. As the whole work of contour bunding and contour trenching was done in 1943 under very many handicaps it was found impossible to pay as much attention to the standards of the bunds on the trenches as for those of the contour bunds. But experience will show that the bunds at the trenches should also be strong enough to withhold the rain water flowing down and damaging the trench bunds and contour bunds lower down. The same formula as for the height of contour bunds will apply to the bund to be put up at the trenches, *viz.*,

$$a = \sqrt{D} + 1$$

where, a is the height of the bund and D is the vertical drop of the contour trench bund. If the slope is 10 per cent and the vertical drop is 6 feet, then the trench spacing will be 60 feet apart and the height of bund at trench must be for 6 inches intensity of rainfall.

$$= \sqrt{6} + 1$$
$$= 2{\cdot}45 + 1 = 3{\cdot}45 \text{ or about } 3\tfrac{1}{2}$$

A three feet height bund then will give only 6 inches free board. In the case of trenching and afforestation the spacing is bound to be small on account of the steep slope and hence the cost of trenching and bunding per acre is bound to be high.

Contour trenching and bunding and raising trees on the trenched soil will improve the forests in the locality and break the monotony

and barrenness of the tops of catchment. In very many cases the top section of a catchment may be rocky, full of boulders and too steep having no soil at all to facilitate contour trenching and afforestation. Such cases should be dealt with carefully and the runoff led away from the contour trenches and contour bunds in the lower sections of the catchment by forming *pucca* bunds at the foot of such rocky portions and leading the runoff to the nearest drain by special channels or catch drains. Such catch drains should be of adequate section and gradient to cope with the runoff to be dealt with.

Fig. 78—CONTOUR TRENCHING

Note that contour trenches are not in straight lines

(Taken from the *Central Board of Irrigation Publication No. 22*)

Fig. 79—GOOD CATCH OF RAIN IN THE CONTOUR TRENCHES CONTINUES TO SEEP INTO GROUND FOR SEVERAL DAYS AFTER THE STORM AND LONG AFTER UNTRENCHED SLOPES ARE BONEDRY

(Taken from the *Central Board of Irrigation Publication No. 22*)

Fig. 80—PARTIALLY RECLAIMED RESERVED FOREST AREA PROTECTED FROM FIRE AND GRAZING—CHITTOOR

Fig. 81—REVEGETATION OF DENUDED SCRUB JUNGLE AT MUNGILPET IN CHITTOOR DIVISION

This area was felled for fuel, closed to grazing for five years and is now opened to controlled rotational grazing. Note bed of a stream with margins held by a good growth of grass. Note elsewhere to the right of the stream the good ground cover stabilizing the slope

Fig. 82—RECLAMATION OF A SMALL GULLY BY REVEGETATION

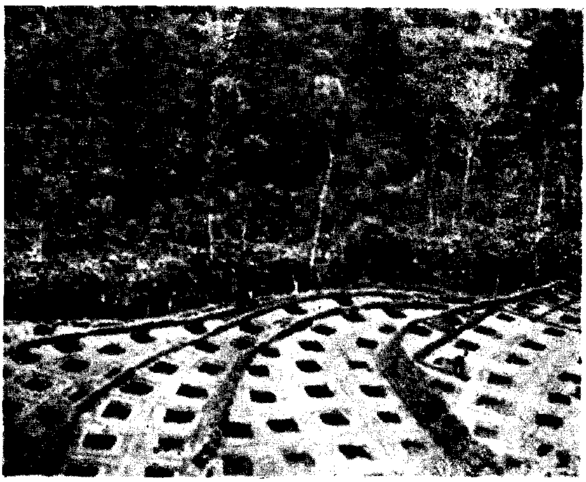


Fig. 83—JAVA: TERRACING AND PREPARATION OF LAND PRIOR TO PLANTING COFFEE

(Taken from *The Rape of the Earth* by G. V. Jacks and R. O. Whyte)

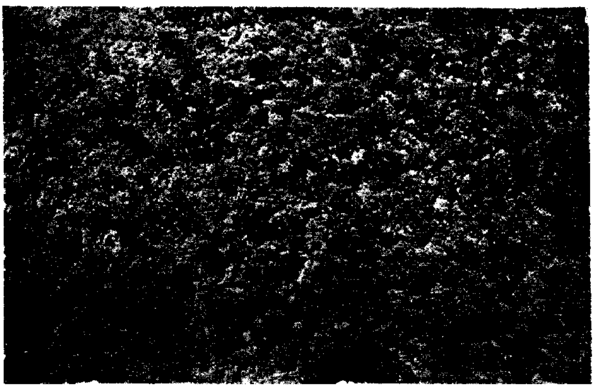


Fig. 84—BRAZILIAN JUNGLE-PICTURE TAKEN FROM THE AIR

Thick cover of closely growing trees

(Courtesy of the *Geographical Magazine* for June 1943)

Fig. 85—Olive trees and orange groves in Crete affording good protection against soil erosion

(Courtesy of the *Geographical Magazine* for January 1944)

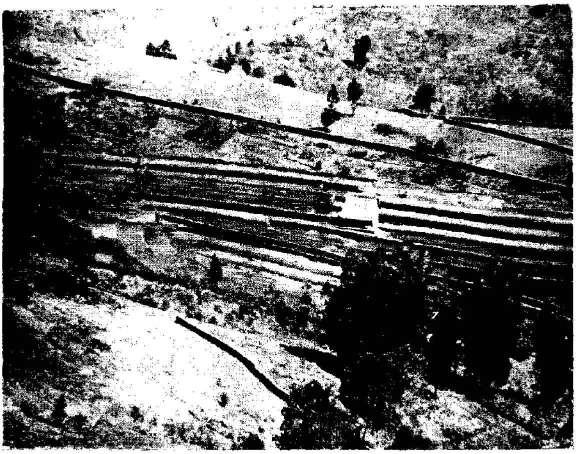


Fig. 86—Bench terraces in Kodaikanal: Palni Hills

Fig. 87—Bench terraces: Palni Hills

CHAPTER VII

DRY FARMING AND TERRACING

Dry farming.—Dry farming is the system of cultivation in which crops are grown purely under rainfed conditions and is widely practised in large areas of the Madras Presidency especially in the Ceded districts. As already stated the average annual rainfall in the Bellary district is about 20 inches. More than half of this is received within a limited period of four to six weeks between September and October. The two main *hingari* * crops, cotton and *cholam* have to depend for their growth on the moisture that is stored in the soil at or about their sowing time which is usually September for cotton and October for *cholam*. Rainfall during their growth period is poor and uncertain. The effective rainfall for the growth of these crops is that received in the period August to October, the normal for the three months being about 12 inches against an annual normal of 20 inches. The object of all dry farming practices is therefore to conserve as much rain water as possible and make it available for crop production. Conservation methods like bunding, scooping or listing help in better utilization of the rain water. The greatest opportunity for conserving moisture in dry soils lies in the reduction of losses due to runoff. All mechanical methods of control of erosion results in the conservation of moisture. The effects of bunding on the conservation of moisture which were studied in detail are described in Chapter V. In heavy soils where rain water has to be impounded for a greater time on the field in order to facilitate its absorption, bunding and scooping are very effective in retaining the rain water and preventing its loss by surface runoff. From quantitative measurements it was shown how scooping reduces erosion losses and how bunding increases the soil moisture content. As we have no control over rainfall we can try by various measures described previously to minimise erosion losses and thus enhance soil moisture, which is the limiting factor in crop production in dry areas.

Terracing.—Terracing and bunding are widely practised on the hills where the gradient of the cultivated fields is very high. Terracing

* Meaning "late sown" as opposed to *mungari* or "early sown."

steep slopes of cultivable lands is one of the many mechanical methods of controlling soil erosion. In sloping country where the rainfall is much, it is not necessary to retain all the rain water on the field and in fact it is also detrimental to the crop if this is done. But what is required is to prevent erosion and dispose of the surface runoff with low velocity.

In principle terracing is essentially a process of constructing a series of drainage channels across the slope of hill sides whose function is to collect the runoff water before it attains harmful velocity and conduct it slowly to an erosion proof outlet. The drainage channels which intercept the runoff and prevent its rapid flow down the slope are formed by throwing up low and broad embankments called terraces.

Three types of terraces are recognized: (1) The guide row, (2) the level bench and (3) the mangum terrace.

(1) *The guide row terrace.*—This is formed by throwing a few furrows together on contour lines into a low ridge. The difference in altitude between successive ridges is about three feet. This is useful for slopes which do not exceed 10 per cent.

(2) *The level bench.*—As the name indicates the level bench terrace consists of a series of benches or flat surfaces running along contours, the difference in altitude between one bench and another depending largely on the depth of soil available and the stope of the land. Each bench has to be cultivated as a separate unit. A good grass covering on the edge of the bench will considerably strengthen the terraces against erosion. The edges of the terraces have to be necessarily left uncultivated in this form of terracing and this is one of the objections for its adoption on gentler slopes. But in hills where cultivation is done on steep slopes this form of terracing is widely practised and is very efficient in the control of erosion.

(3) *The mangum terrace.*—This is used extensively in the United States of America for the control of sheet erosion in large fields with gentle slopes. It consists of a broad ridge 15 to 24 inches high running along contours. It is formed by ploughing several furrows along the surveyed line and heaping the soil on the lower side so as to form a low ridge with a depression on the upper side of the ridge. Instead of the terrace being flat it is given a gentle gradient of about 6 inches in 100 feet towards some natural outlet into which the water may drain. The ridge is kept very wide at the base so as to allow of continuous cultivation over the whole field. The vertical drop between terraces is usually half the slope of the land per 100 feet; it depends also on the nature of the soil. Drainage of runoff water is a very important factor in terracing. Drains with

gentle slope reduce the velocity of the flowing water. Contour drains with a gentle gradient like the ones used for the mangum terrace are very effective in reducing erosion losses.

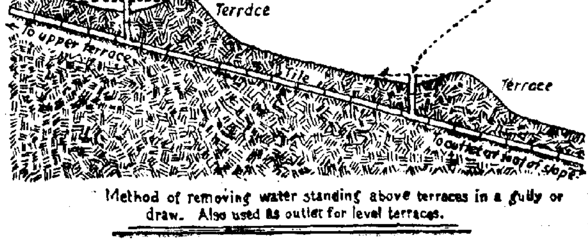
Terrace design consists of selection of site, location of terraces, spacing them with reference to the slopes, designing the channels for water section, for bed slope and for strength of embankments, delivering the runoff between two terraces through a strong outlet into the drain, preservation of terraces or ridges, preservation of the channels, etc. The subject is elaborate and so brief mention of a few simple rules relating to the design is made here.

Terrace spacing.—One simple thumb rule for the spacing of one terrace to another expressed in feet of vertical drop is—

$$\frac{\textit{Add 3 to the percent of slope}}{2} = \text{Fall in feet, and this rule is}$$

fairly accurate up to slopes of 6 per cent, e.g., if the country slopes at 4 per cent, the terraces should be spaced at $\frac{3+4}{2} = 3\frac{1}{2}$ feet drops. Terrace spacing recommended for Alabama Georgia conditions in the United States of America is given in the following table:—

Slope of land feet per 100 feet.	Vertical distance of drop between terraces. FEET.	INCHES.	Horizontal distance between terraces.	Slope of land feet per 100 feet.	Vertical distance of drop between terraces. FEET.	INCHES.	Horizontal distance between terraces.
1 ..	2	6	180	7 ..	4	0	57
2 ..	2	9	140	8 ..	4	3	53
3 ..	3	0	100	9 ..	4	6	50
4 ..	3	3	80	10 ..	4	9	48
5 ..	3	6	75	12½ ..	5	4	43
6 ..	3	9	63	15 ..	6	4	40



Method of removing water standing above terraces in a gully or draw. Also used as outlet for level terraces.

Fig. 88

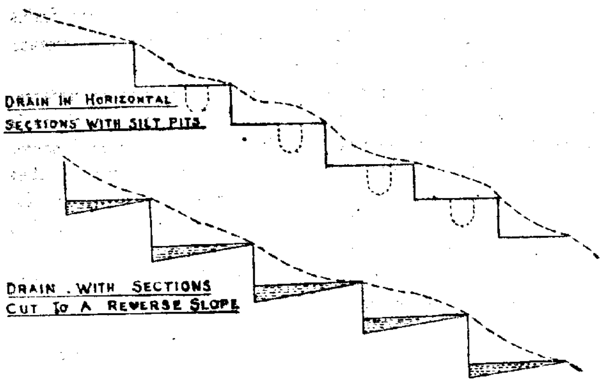


Fig. 89—DRAINAGE DEVICES

The United States Department of Agricultural Bulletin No. 1669 recommends the following spacing for slopes up to 10 per cent or less for level terraces :—

—	Vertical drop in feet between	—	Vertical drop in feet between
Sandy soil	4·5	Clay loam	2·5
Sandy loam	3·5	Clay	2·0

The terrace channel can safely be designed from Manning's velocity formula $V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$ where, V = Velocity in cusecs, R = H.M.R. (Hydraulic mean radius), S = slope, and n = co-efficient of rugosity depending on the surface, regime of the channel, etc., and $Q = AV$ where Q is the discharge in cusecs and A is the area of water section.

Values of n *in Manning's formula.*

Surface.	Perfect.	Good.	Fair.	Bad.
Canals and ditches—				
Earth, straight and uniform ..	0·017.	0·02	0·0225	0·025
Canals with rough stoney beds weeds on earth banks.	0·025	0·03	0·035	0·04
Natural stream channels—				
Clean straight bank	0·025	0·0275	0·03	0·033
Winding and clean	0·033	0·035	0·04	0·045
Winding with stones and weeds.	0·035	0·04	0·045	0·05
Sluggish river reaches	0·05	0·06	0·07	0·08
Very weedy reaches	0·075	0·10	0·125	0·15

Terracing as a soil conservation measure in hilly country where the rainfall is in excess of 40 or 50 inches can profitably be taken up in the Madras Presidency also especially in the West Coast districts.

CHAPTER VIII

CONSERVATION OF GRASS LAND

In Madras we have very few cultivated grass pastures such as are found in many other lands. Such natural pasture as exists is found in the unreserved forests and *porambokes* of villages, and in the reserved forests. When forest reservation was first carried out some 40–50 years ago, large areas were excluded from reservation and left as common lands on which village cattle could graze. With the expansion of cultivation, these areas have been reduced with the result that the pressure of cattle has increased and to-day they are little more than exercising grounds. In the reserved forests the provision of pasture for cattle wherever required is always an avowed object of management. But until recently pasture management has received little attention and grazing has been provided at nominal rates without any consideration of the carrying capacity of the pasture. This has resulted in deterioration and denudation of grass cover followed by inevitable heavy runoff and soil loss. This loss has a cumulative effect in still further reducing the quantity of grass forage and preventing also the natural regeneration of tree species. With the loss of grass, the herdsman is thrown more and more to the trees for fodder for his cattle. These he lops ruthlessly. In the more remote forest areas where grass cover is still satisfactory and the pressure of grazing comparatively light, the heavy growth in the monsoon dries with the advent of the hot weather and becomes unpalatable to cattle. Burning of this grass results in a green flush of young grass for a short period and is often resorted to by graziers for this reason. Burning however again removes the vegetative cover and leaves the soil open to serious wash with the pre-monsoon showers which are always heavy in intensity. The combination of over-grazing and forest fires is responsible in no small measure for the poor condition of the reserved forests in the dry districts to-day.

The conservation of forest pastures does not permit of heavy expenditure and in fact such expenditure is unnecessary. Experience shows that if a degraded forest pasture is closed to grazing, recovery of ground cover is remarkably quick and this is followed

very slowly by an improvement in natural regeneration of tree species. This is demonstrated by the effect of closure in young fuel coupes which is prescribed in all forest working plans to allow the tree coppice to grow out of reach of cattle. Improvement continues for a period of approximately 3 years, by which time the average area is well stocked and quite capable of carrying two to three times the number of cattle it could tolerate in its degraded state. It is not always possible however to close extensive areas completely to grazing to bring about this rapid improvement and such closures should normally be limited only to areas where denudation has resulted in dangerous erosion.

Other methods have been discovered which also result in improvement of degraded pastures while still allowing grazing to take place. These depend entirely on controlling the grazing animal. The first is known as deferred grazing. In this method, the grass is not grazed until it has seeded thus taking advantage of the full seed crop. Once seeding has taken place the pasture is grazed and the seeds are well trodden into the ground by the cattle to germinate and grow with the next monsoon. The method has been tried and has proved successful in Madras, but since it means closure of the forest for a large part of the year against all animals it is not applied extensively.

Of much more importance is the second method known as rotational grazing. This method is based on the fact that continuous grazing by a small number of animals is far more detrimental to the pasture than intermittent grazing by a larger number of cattle. Take an area of 100 acres for example. Under continuous grazing this could provide fodder for approximately 25 cows. This herd would range over the whole area, grazing for preference the more palatable grasses first. While grass cover would be maintained, the better grasses would be gradually ousted by the less palatable since the former are more heavily grazed. Under rotational grazing, the area would be divided into four or five paddocks and the herd would graze only in one paddock at a time, other paddocks being given rest. During the resting period all possible species of grass have time to recover. The herd moves round from paddock to paddock. Experience has shown that if such a rotation is followed, the result is an increase in fodder production and that where originally only one cow per 4 acres could be admitted to graze, this capacity can be increased after one year or two years to 1 cow per 3 acres or even per 2½ acres. In one forest division in Madras, the ryots willingly pay three times the ordinary grazing fee for the privilege of being allowed to graze rotationally in pastures which have been improved by this method.

Deferred and rotational grazing cannot be introduced over the whole of the thousands of acres of forest pasture by a stroke of the pen, however, and while it is extended as fast as conditions permit, it is necessary to take steps to see that the whole area is protected as far as possible from denudation of ground cover. This can only be done by dividing the pastures into natural blocks and limiting the number of cattle admitted to the grazing capacity of the block.

CHAPTER IX

CONTROL OF SHIFTING CULTIVATION ON HILL SLOPES

WITH THE Aryan migration and occupation of the better cultivable lands of India, the aborigines were gradually forced into the hills. Here they found that it was possible to live and cultivate crops with a minimum of trouble. The soil under the hill forests was excellent and it was only necessary to fell the forest, burn off the debris and scratch the soil with hand implements to get good crops. After several years however the soil became exhausted chiefly by the washing away of the top soil in the rains and partly because no manuring was done. Hence it was necessary to move on and repeat the process. This practice became known as shifting cultivation or by other local names such as *ponam*, *tuckle*, *kumri*, etc. This practice is destructive. When an area is vacated a secondary forest growth appears on the impoverished soil, but this is far inferior to the original forest. It results in the restoration of fertility to some extent after a long period of years, by which time it is again felled and cultivated leading to further loss of soil. So the process goes on until the soil reaches a stage of exhaustion where further cultivation is no longer possible and the area is left, usually a shallow skin of poor earth over bed-rock, which will take centuries to recover even under the most favourable treatment. The shifting cultivator then gradually encroaches on other areas. Owing to such habits over centuries past thousands of acres of what was originally good protective forest have been destroyed or reduced to poor scrub jungle. Realizing the consequential damage to the public interest, shifting cultivation has now been brought under control in all reserved forest but it still exists in the Agencies, and on the West Coast in privately owned forests.

The primitive peoples such as the *Kaders*, *Kurumbers*, *Irulas*, *Sholagas*, etc., cannot however be stopped from cultivating altogether. They must grow their own food as they have no money to purchase it. Their habit of shifting cultivation is therefore being made use of under careful control to their own and to the public advantage, turning the practice from a destructive into a productive channel.

Fig. 90—JAVA; RICE CULTIVATION IN TERRACES

(Taken from *The Rape of the Earth* by *G. V. Jacks* and *R. O. Whyte*)

Fig. 91 EXAMPLE OF TERRACING IN CETINJE IN MONTENEGRO

(Courtesy of the *Geographical Magazine* for January 1944)

Areas of natural forest are taken up on a prepared plan and are felled and cultivated in the usual way, but the cultivators either sow or plant out tree species with their crops. By the end of two or three years the trees have grown sufficiently to make further cultivation impossible and the area is vacated, leaving a good forest cover of selected species. Every year an area is absorbed and an equivalent area vacated to be placed under a silvicultural regime of thinnings and whole zones are thus gradually regenerated. This system was first developed in Burma where it is known as *taungya* and is the system by which thousands of acres of excellent teak plantations have been raised. It is in vogue in Madras under the various names *kumri*, *ponam*, *tuckle*, etc., and in its most advanced form has been applied to the dry degraded fuel forests. These dry forests are the greatest technical problem of the Madras Forest Department. The regeneration of teak in the moist forests of Malabar has been mastered and reduced to a fine art. The regeneration of scrub jungle is a different matter. Rainfall is precarious and mal-distributed while these forests have to be developed so as to meet the many and varied demands of the local population chiefly rural. The provision of grazing for example, ranks in equal importance with the production of small timber, fuel, bamboos, etc. For half a century highly trained forest officers attempted the regeneration of such areas with little success. It is only during the last decade that success has been achieved and it has been possible to study the various factors which combine to make regeneration operations successful. At the present time more and more areas are being dealt with by raising tree crops in combination with agricultural crops. It is found that the radical opening of the topsoil caused by the ploughing, fixes a large proportion of the rainfall instead of allowing it to run away, and this is sufficient to give the various tree species a good start from the first year of sowing. The phenomenon known as dying back is becoming increasingly rare and the xerophytic species naturally found on dry areas which used to take several years to establish before real growth started: now put on height growth from the start. In dry areas cultivation can be carried on for 3 or 4 years, and even longer with manuring according to the rate of growth of the tree crop. With the last agricultural crop it is advisable to sow grass seed which covers the ground as an aftermath to the harvest of the main crop.

Kumri is however a very dangerous operation from the point of view of erosion. Unless adequate precautions are taken, the heavy irregular showers result in heavy runoff and soil wash. This is the case in certain soils even on slight gradients of even 1 in 100. It is necessary therefore to hold up runoff by contour trenches, ditches

or stone bunds as already described and to combine this with gully plugging to hold up as much silt as possible. Within economic limits, the more this work is done the better. It is a permanent improvement to the area and can be regarded in the same light as expenditure on a well when converting dry into garden lands, since it increases the available moisture in the soil.

Though the above details of the *kumri* or *taungya* method of treating forests may seem out of place, it is given to show the useful productive work that can be done if the shifting cultivators can be diverted to it. The total area of reserved forests in Madras is about 18,000 square miles, including village or panchayat forests, out of a total area of 124,000 square miles, and much below the 20–25 per cent which is the limit considered satisfactory in more advanced countries. Of this 18,000 square miles, some 8,000 square miles in the dry districts are available for improvement on these lines. Such work alone could absorb not only the whole of the shifting cultivators in the Madras Province but also a large proportion of the so-called landless poor, the latter as much or even more of a problem than the former.

In dealing with the subject, it will no doubt have been realized that while soil conservation measures may be taken by the Government on public lands and while good farmers may carry out such simple work as bunding their holdings, it is not economical for owners of lands on steep slopes to-day to take such measures. Reference has also been made to the mistake of ever alienating such lands, the outer slopes of the Nilgiris being an example cited. Where the clearing of natural cover on such lands has already been done, the damage is irreparable. Where clearing has not been affected, however, the Government of Madras have the power to regulate or prohibit the pasturing of cattle, the firing or clearing of the vegetation and the breaking up and clearing of the land for cultivation with a view to prevent the erosion of the soil. This can be done under the existing forest legislation in the Province, namely the Madras Forest Act No. V of 1882. The owners of any land who wish to form forests or conserve forests thereon can also ask the Government to help them in achieving their object by applying the provisions of the Forest Act to their lands.

CHAPTER X

OTHER METHODS OF CONTROLLING SOIL EROSION AND SURFACE RUNOFF

CONTOUR BUNDING, contour trenching and terracing described in the foregoing chapters are all mechanical ways of preventing or minimising soil erosion and these may be likened to curing a patient by operation. The other methods of control of erosion by regulated forestry, regulated grazing, re-vegetation, cover cropping, mixed farming, crop rotations, strip cropping, etc., are biological and may be likened to treating a disease by dieting or reinforcing good health by temperate living.

Experiments are being conducted in the Sholapur Farm and Bijapur Farm in the Bombay Presidency on strip cropping, crop rotations, mixed farming, cover cropping, etc., and to some extent in the Hagari farm in the Madras Presidency also and when results are arrived at they would prove useful to the cultivator for practice along with other methods of improved scientific dry farming to conserve soil and increase crop output.

Suggested use of land to control erosion (as affected by slope and degree of erosion).

Group.	Erosion.	Cropping and erosion control practices.
A 2 per cent slope.	Slight ..	Agricultural crops with rotation and contour farming.
	Moderate ..	Agricultural crops 3 to 4 years rotation (1 to 2 years hay) and strip farming.
	Severe ..	Agricultural crops—Terracing supplemented with fertilization, rotation and contour farming.
B Slope 2 to 12 per cent.	Slight ..	Agricultural crops—Terracing, supplemented by 3 to 4 years of rotation.
	Moderate ..	Agricultural crops—Terracing supplemented by 5 to 6 years rotation (2 to 3 years hay) and strip farming.
	Severe ..	Agricultural crop—Terracing supplemented by 5 to 6 years rotation (3 to 4 years hay) fertilization and strip farming).

Group.	Erosion.	Cropping and erosion control practices.
C Slope 12 to 20 per cent.	Slight ..	Close growing crops for seeds and hay or pasture. If necessary cultivated crops on flatter slopes with 5 to 6 years rotation and strip farming 60 per cent or more in sod farming strips or reforestation.
	Moderate ..	Legumes or grass for hay or pasture, moderate grazing.
	Severe ..	Permanent legumes or grass for hay only with fertilization or reforestation.
D Slope 20 to 30 per cent.	Slight ..	Legumes or grass for hay or pasture, moderate grazing, forestry.
	Moderate ..	Perennial legumes or grass, for hay only, forestry.
	Severe ..	Forestry or natural vegetation, no grazing.
E Slope 30 per cent.	Slight ..	Perennial legumes or grass for hay only on flatter slopes—Forestry.
	Moderate ..	Forestry or natural cover, no grazing.
	Severe ..	Do. do.

The above are general recommendations. Individual needs are to be worked out with the agronomists and soil specialists. Group E practices can be used on group D slopes or group D on group C but not *vice versa*. Use of cultivated crops should be discouraged and entire fields with slopes over 12 per cent should not be ploughed up at the same time unless terraced. Usually grazing should be discouraged as far as possible. Any ploughing should be done only in strips on contour lines and several years required to plough or re-seed entire field.

NOTE.—*Erosions*: *Slight*—Less than 25 per cent surface soil removed; *Moderate*—Twenty-five to 75 per cent of surface soil removed; *Severe* More than 75 per cent surface soil removed.

Biological methods of erosion control.—Control of erosion through crops or vegetation is the biological method of control. Vegetation is nature's protection against erosion. As stated already a cover of grass was found to be about five times more effective than bare soil in the control of runoff waters and 65 times more efficient in the control of soil losses. It is only when the natural vegetation is removed and land put under cultivation that erosion becomes excessive. But this is a necessary step in raising crops. Having put the land under cultivation we should take all possible measures to see that erosion is kept at a minimum. The principle of biological control of erosion is that cultivation of crops should be done in such a way that the maximum protection to the soil is offered for as long a period as possible during the rainy season. The effect of a cover crop on the control of erosion is considerable.

Fig. 94—Pure cotton rows permit erosion

Fig. 95—Strip cropping

3 cotton lines and 6 lines of *Setaria* alternate

Fig. 96—GULLY TO BE USED AS TERRACE OUTLET

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 97—EFFECT OF A BRUSH DAM

Here is shown the effect of a brush dam in catching sediment and in controlling erosion

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 98—Gully treatment with brush

These brush dams have caused silting and have prevented further erosion. This gully is almost ready for seeding to a mixture of legumes and grasses

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 99—Gully control with brush

Note the sediment caught and held by brush

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

In the runoff plots at the Hagari farm described on page 33, studies were made on the effect of having a cover crop of groundnut on the control of erosion. Groundnut (A.H. 25) spreading variety, was sown early in June and harvested in December 1940. The following results were obtained:—

Results of runoff for 1940–41.

(Data collected between 13th June and 13th December 1940, the date of sowing and harvest of groundnut respectively in one of the plots.)

—	Control plot clean fallow.	Cropped with groundnut.
1 Number of days when there was runoff ..	11	5
2 Total rainfall on days on which runoff was recorded in either of the plots ..	7·63	7·63
3 Rain-water lost in inches	2·81	1·65
4 Silt washed in tons per acre	1·83	0·98

The number of days when there was runoff was 11 in the clean fallow plot while it was only 5 in the cropped plot. Losses of water and soil are also reduced by nearly 50 per cent in the plot with the cover crop of groundnut. The effect of the cover crop in the reduction of runoff is threefold, viz., (1) interception of rainfall by the crop reduces the intensity of rain drops reaching the soil; (2) the spread of crop offers mechanical obstruction to the flow of water; and (3) absorption of moisture by the crop reduces the cropped plot to a drier state than the uncropped one and the soil will readily absorb moisture in a dry state. This will tend to lessen runoff. For these reasons losses of soil and water by surface runoff in the plot with a cover crop of groundnut were reduced to nearly half those occurring in the control plot. It will, therefore, be advantageous to have strips or belts of a cover crop that will be on the field during the rainy season in areas that are subject to erosion.

From studies based on the time taken for completely eroding a block of soil (40 inches by 20 inches by 4 inches approximate volume of soil being about 1·85 cubic feet), containing different cover crops under a definite pressure head it was found that in resisting erosion cotton was 1·6 times more efficient than bare soil, *Setaria* (pure) was 3·3 times, groundnut was 5 times and *pillipesara* 11·8 times more efficient than bare soil. The times taken for eroding the block of soil under the different cover crops were correspondingly greater than those taken for eroding a block of bare soil. The greater the spread of the crop the greater is its value as a cover against erosion. Wide spaced and clean tilled crops like cotton offer the least resistance to erosion while close growing crops like *Setaria* or groundnut offer the maximum resistance to erosion.

Effect of crop rotations.—Rotation of crops as practised in most areas tends not only to reduce erosion but also to increase the fertility of the soil. If the same crop is grown on the land year after year there will be a fixed type of cultivation and this tends to increased erosion losses especially in the case of clean tilled crops like cotton or sorghum. The soil between the rows of these crops has to be kept free of weeds by intercultivation and this practice generally increases erosion. The more intense the cultivation of the land, the greater is the erosion. Besides, by having the same crop the soil is impoverished being depleted of plant food in the same layers of soil. Hence, if crop rotation is practised, the intake of plant food material takes place from different layers in the soil and helps considerably in preventing soil exhaustion. It is, therefore, not unusual to include a leguminous crop in the rotation with a view to increase the nitrogen content of the soil. There is no common rotation that can be adopted in all tracts of the Presidency as the cropping is decided mostly on the existing soil and weather conditions; but rotation of crops is very common in most areas. The following are a few examples of crop rotations practised in the different districts:—

Tobacco—cotton—chillies	In Guntur area.
Setaria—cotton—sorghum or Sorghum—Bengalgram—cotton ..	In the black soils of Bellary.
Sorghum—cotton—redgram and tenai mixtures or Sorghum—pulse—cotton	In Coimbatore area.

Not more than one crop occupies the field in any one year.

Strip cropping.—Strip cropping is one of the best examples among methods of biological control of erosion. The principle of strip cropping is that strips of erosion permitting crops should be alternated with strips of erosion resisting crops. The actual crops that appear in the strips depends on the existing cropping conditions in the locality. In the black soil areas of the Ceded districts mixtures of *Setaria* and cotton are sown in the *mungari* or early season. These can conveniently be replaced by strips of *Setaria* and cotton; six lines of *Setaria* to three lines of cotton are found to be an economical proportion between the rows.

Contour planting of crops is another example of the biological method of control of erosion and is advocated particularly on the hills. Generally, contour cultivation combined with contour planting go a long way in arresting runoff, although they should be combined with practices like terracing, bunding, etc., in order to secure greater protection in very slopy fields.

CHAPTER XI

CONTROL AND ELIMINATION OF GULLIES

GULLYING GENERALLY follows the loss of surface soil through sheet erosion. The principal causes of sheet erosion are the removal of the protective covering of vegetation from soil surface followed by cultivation and overgrazing without proper provision for arresting the excessive resultant runoff. The other contributory causes are cultivation up and down the slopes, alignment of faulty water-courses, livestock trails and mining operations. During the progress of agricultural operations, it is not always possible to anticipate heavy precipitation and be prepared to meet the damaging influence of the torrential rains on exposed soil. Extremely large quantities of water from heavy rains, pouring down over slopes, especially if carrying sharp and angular stones, cut gullies in meadows and pastures.

It is always a wise rule to prevent formation of gullies than to control them after they are formed. However due to certain causes beyond human control, gullies do form and it is in this connexion that gully control measures have to be adopted. Gullies may be generally classified as (1) channel gullying; (2) waterfall gullying.

Channel gullying.—When going to and from a hillside pasture land cattle traverse the same unobstructed track until a smooth sloping pathway has been formed. Cart-tracks in open country have also the same effect. These pathways usually are winding in nature and cut across the slopes. Rain water coming down the slope is intercepted by these beaten tracks. The water gets concentrated in these paths towards the base of the slope to such an extent as to give the water high velocity and tremendous erosive power. Gullies are the result. The size and shape of such gullies depend upon the soil, subsoil, gradient, rainfall and size and shape of the contributing watershed. The depth and type of channel gullying primarily depend on the character of the soil. If hard rock is met with near the surface, the gullies will be shallow and wide. If the subsoil consists of plastic and resistant clay, shallow V-shaped gullies are the result. If the subsoil is soft and easily friable, then U-shaped gullies of very great depths are easily cut.

The best treatment of a given gully depends upon its location and dimensions, gradient, cover and drainage conditions of catchments, intensity and volume of rainfall and upon whether the gully has to be filled and restored to crop-use or partially filled and used as a drainage channel or merely protected against further erosion.

When once gullies are formed, they develop very quickly if unchecked scouring is allowed to continue. Longitudinal development is faster than breadthwise development on account of the greater volume of water cutting at the head. The longitudinal development will stop at the dividing watershed and afterwards depth and width will increase. The rate of growth is much faster on steep hill slopes. To prevent such gully formations obstructions such as brush or any other useless material may be placed in the paths. If the formation and use of pathway cannot be avoided, as in narrow up-and-down hill slopes the edges of the path are cut at short intervals to enable the water from the paths to drain on to the adjacent pasture land.

Waterfall gullying.—Waterfall gullies have their origin in small vertical drops at the lower end of an erodible depression. The impact of the falling sheet of water wears away the underlying material and creates a local scour into which the overhanging sides fall in. This procedure gradually creeps up the slope. As the gully advances up, the depth of fall increases as the water flowing in the channel below the drop tries to cut a flatter gradient which depends upon the erodibility of the soil.

Usually such waterfall erosions are met with on the banks of natural streams. The runoff from the sloping sides of the banks cuts deep ravines especially in places where the sub-surface material is highly friable. Such ravines are sometimes 50 to 60 feet in depth. These ravines as they cut back meet with subsidiary water courses which form tributaries. Gradually a network of gullies cut the entire watershed. These gullies are called U-shaped gullies as their width is fairly large in proportion to their depth. They are also otherwise known as overfall and gully head erosion. They sometimes develop very quickly depending on the erodibility of the sub-soil and the volume of water draining into them and the height of overfall. In gully heads, this kind of erosion has to be immediately attended to as otherwise such scours extend rapidly by caving-in.

Control of gullies.—In farm lands of varying stages of gullying it is logical to protect first the best portion of the land from further damage. When the cost of gully control exceeds the value of land protected, the work is not justifiable unless it protects adjacent or downstream lands, reservoirs, waterways, buildings or other property. In appraising the value of such works it is extremely important to

recognize the fact that a relatively small gullied area may constitute a serious menace to downslopes or downstream lands as well as channel ways, reservoirs and harbours. Many gullied areas in a big watershed may have a cumulative effect on floods and silting of channel ways.

After a gully has cut its way to the head of the watershed, it practically ceases to be active. In such cases, if the ravine is protected from cattle, natural vegetation will thrive and establish the required protective cover. But if a gully is in the initial stages of development it is highly important that protective measures are undertaken immediately to prevent damage to adjacent fields.

The general principles of erosion control apply to the control of gullies also. The best way to control a gully is to plant the entire ravine with stabilising vegetation. The type of vegetation and the method to be adopted for its satisfactory growth will depend on soil, local climate and topographic conditions. Even if the whole gully cannot be taken up for planting it is necessary to stabilise the head first.

Often the soils exposed in eroded gullies are unsuitable for plants to take root. In such cases, the required soil cover over the bed has to be provided through the help of temporary check dams, and by growing suitable species of grasses and other plants. The runoff from the catchment during the time the plants take first growth has to be carefully handled. Heavy runoffs have to be diverted through channels specially formed for the purpose. In cases where large volumes of water have to be handled through the gully during stabilization, permanent structures should be utilized.

Bennet (1939) has adopted the following classification for sizes of gullies :—

Small gully—less than 3 feet in depth.
Medium gully—3 to 15 feet in depth.
Large gully—more than 15 feet in depth.

He has classified the size of contributing drainage area as follows :—

Small drainage area—5 acres or less.
Medium-sized drainage—5 to 50 acres.
Large drainage area—more than 50 acres.

A further classification of watershed depending on slope as given by *Ayres* (1936), is as follows :—

Hilly or steep—10 per cent slope or more
Rolling or medium—5 to 10 per cent slope.
Slight—0 to 5 per cent slope.

The rate and volume of runoff determine the method of gully control. The following methods of handling runoff are important in gully control:—

(1) Retention of rainfall on watershed.

(2) Diversion of runoff from the gully.

(3) Safe conveyance of runoff through the gully.

Retention of rainfall.—Soil and water conservation methods considerably reduce runoff. In regions of light rainfall where the slope of the watershed is gentle and the soil is absorbent, contour bunding and terracing with closed ends are sufficient to retain the rainfall on the soil and no other special mechanical measures will be necessary for gully control.

Small and medium gullies in fallow lands can frequently be controlled by placing a series of earth fills across the gully channels judiciously located according to the gradient of the land. Several grasses like Marvel (*Andropogon annulatis*), Guinea grass and Napier grass when planted across gullies and surface drainage courses have been found to be very effective in preventing loss of soil by erosion, though they allow extra runoff to escape.

Diversion of runoff.—In the case of gullies of all sizes excepting those in small catchments runoff should first be diverted from the head of the ravine before control measures are undertaken. By terracing the drainage area above the gully head, much or all of the runoff can be diverted to a safe outlet. Small gullies can be eliminated by putting up cross terraces. Where soil conditions are such that vegetative cover cannot be easily got, terracing or the use of diversion ditches are the only practicable methods of control. Diversion channels are efficient in forest and grass covered areas. Below unprotected cultivated lands they are likely to be choked up with erosion debris unless a filter strip of vegetation is established above the ditch.

In designing a diversion channel care should be taken to see that its size is sufficient to carry all the drainage water from the contributing catchment and the gradient is such that the runoff will flow with non-erosive velocity.

To ascertain critical runoff from small catchments, Ramser has proposed the following rational formula [*Ayres* (1936)]:—

$$Q = C.I.A.$$

Where, Q = critical rate of runoff in cubic feet per second;

C = runoff coefficient representing ratio of runoff to rate of rainfall;

I = rainfall intensity in cubic feet per second per acre which unit happens to be approximately identical with rate of rainfall in inches per hour;

A = area of watershed in acres.

He has suggested the values of C as follows:—

Kind of watershed.	Values of C.
Cultivated rolling 5 to 10 per cent slope	0·60
Cultivated hilly 10 to 30 per cent slope	0·72
Pasture rolling 5 to 10 per cent slope	0·36
Pasture hilly 10 to 30 per cent slope	0·42
Timber rolling 5 to 10 per cent slope	0·18
Timber hilly 10 to 30 per cent slope	0·21

NOTE.—These values are applicable to small areas not more than 1,000 acre.

For larger catchments the combined value of C taking into consideration different kinds of watersheds may be as follows:—

Area of catchment in square miles.	Values of C.
2 to 5	0·2 to 0·3
6 to 50	0·1 to 0·2
50 to 200	0·05 to 0·1

In the Madras Province, there are no rainfall statistics which give maximum intensities of rainfall per hour or lesser periods. The statistics give average rainfall for a period of 24 hours. A statement of average monthly rainfalls in various parts of this Province with the maximum recorded intensity in 24 hours will be found in the Appendix. This rainfall converted into average fall per hour does not give the actual maximum intensity of precipitation which is required for designing diversion channels in small and average-sized catchments. In average-sized catchments up to 5 square miles in extent, generally it will be sufficient if maximum intensity of rainfall is taken as 2 inches per hour for purposes of design, though actually in some rare instances this figure has been surpassed.

Knowing the quantity of runoff that is to be provided for in the diversion channel, the size and gradient can be fixed. Many formulæ have been propounded for determining the velocity of water flowing in an open uniform channel. The following notations are used in the formulæ:—

a = area of cross-section of waterway in square feet.

p = wetted perimeter or length of wetted border in feet.

$R = \dfrac{a}{p}$ = hydraulic mean depth in feet.

S = Sine of the angle of inclination of the water surface.

C = a coefficient.

n = a coefficient of roughness; that is, a coefficient which depends on the nature of the bed and sides of the channel.

V = mean velocity of flow of water in feet per second.

The fundamental formula on which all calculations of flow of water in open channel is based, is—

$$V = C\sqrt{RS}$$

The value of C has been calculated by different people in various manner. Only important equations are noted below:—

(1) *Bazin's* new formula is $V = C\sqrt{RS}$, where $C = \dfrac{157{\cdot}6}{1 + \dfrac{n}{\sqrt{R}}}$

The value of n varies with the nature of the channel, thus:—

- 0·109 Very smooth—Smooth cement plastered, planed timber.
- 0·29 Smooth—planks, ashlar, brick.
- 0·83 Rough—Rubble masonry.
- 1·54 Rougher—Earth newly dressed, or pitched in whole or in part with stone.
- 2·36 Very rough—ordi ary earth channels.
- 3·17 Excessively rough—canals encumbered with seeds and boulders.

(2.) *Gangulette* and *Kutter* have evolved a coefficient taking into consideration the slope factor also. It is

$$C = \frac{41{\cdot}6 + \dfrac{1{\cdot}811}{n} + \dfrac{0{\cdot}00281}{S}}{1 + \left(41{\cdot}6 + \dfrac{0{\cdot}00281}{S}\right)\dfrac{n}{\sqrt{R}}}$$

in which n is a coefficient of roughness. The following are some of the values of Kutter's n:—

n—
- 0·009 well planed timber.
- 0·010 Pure cement plaster.
- 0·013 Ashlar, good brick work, iron pipe in ordinary condition.
- 0·015 Rough brickwork—Well dressed stone masonry.
- 0·020 Rough rubble in cement, stone pitching, large canals carrying 400 cusecs and upwards maintained in good order in smooth soil.
- 0·0225 Canals carrying less than 400 cusecs, well maintained in good order in smooth soil.
- 0·025 Rivers and canals in perfect order free from stones or woods.
- 0·030 Rivers and canals in good order having stones and weeds.
- 0.035 Rivers and canals in bad order.

The Kutter's formula can be re-written in the following manner :—

$$V = \frac{N\;R}{\sqrt{R} + D}, \text{ where}$$

$$N = \left(41{\cdot}6 + \frac{1{\cdot}811}{n} + \frac{0{\cdot}00281}{s}\right)\sqrt{S}$$

$$D = \left(41{\cdot}6 + \frac{0{\cdot}00281}{S}\right) n$$

Colonel E. S. Moore, has prepared extensive tables on the basis of these coefficients which are very handy in the design of channels.

Fig. 100—BUILDING A BRUSH DAM (1)

The posts are in place for one-row post brush dam

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 101—BUILDING A BRUSH DAM (2)

The brush has been placed and wired down under the poles

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

6**

Fig. 102—Brush dam completed (3)

The dam has been completed and wet straw placed [for catching the silt washed from the fields above

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

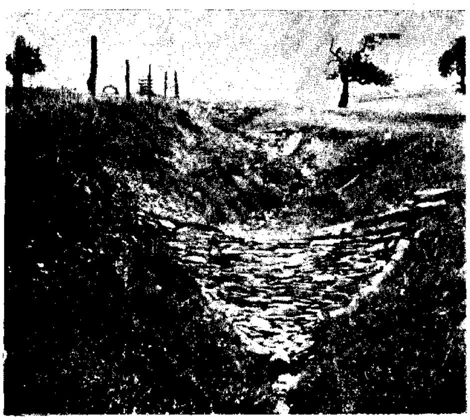


Fig. 103—Diversion-ditch outlet

Honeysuckle (brush type) is planted on the raw banks near the stone dams. In Southern New York

(Taken from *Conservation of the Soil* by *A. F. Gustafsou*)

Fig. 104—Manaturai vari in Pudukkottai State: Bandy track forming gully and sheet erosion

(By the courtesy of the Pudukkottai Durbar)

Fig. 105—Manaturai vari in Pudukkottai State: Showing denuded rock and cart-track forming gully

(By the courtesy of the Pudukkottai Durbar)

Based on the Kutter's formula, diagrams have been prepared by *Captain A. F. Garrett* from which required particulars for channel design from known variables can be read at a glance. Kutter's formula in spite of its being cumbersome, is the only one that is extensively used by Irrigation Engineers in India for channel design.

(3) *Manning's* **formula in use in America is $V = C\sqrt{RS}$ where the value of $C = \frac{1{\cdot}4858}{n}\sqrt[6]{R}$ in which n has the same value as in Kutter's formula.**

This formula can be re-written as—

$$V = \frac{1{\cdot}4858}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

This formula is very handy and requires better consideration at the hands of Irrigation Engineers in India.

Artificial channels in earth are commonly trapezoidal in section, the side slopes being determined by the stability of the soils. The slope usually adopted for channels in cutting is 1:1 or $1\frac{1}{2}$:1. After running for some years, earthen channels tend to assume side slopes of $\frac{1}{2}$:1. So, in calculating discharges from various formulæ it is usual to assume the side slopes of the channel as $\frac{1}{2}$:1 though actually during execution the slopes may be different.

The following table has been prepared for different depths of flow for non-scouring velocity as given by kennedy's equation $V = 0{\cdot}84\, d^{0{\cdot}64}$. The side slope assumed for the purpose of design is 1/2 : 1. The Kutter's value of rugosity co-efficient for channels carrying discharges up to 400 cusecs is assumed as 0·0225.

Depth of flow in feet.	Velocity in feet per sec.	Bed width in feet.	Bed fall or surface fall for Kutter's n = 0·0225 slope 1 in.	Depth of flow in feet.	Velocity in eet per sec.	Bed width in feet.	Bed fall or surface fall for Kutter's n = 0·0225 slope 1 in.
For 5 cusecs discharge.				*For 15 cusecs discharge.*			
0·75	0·54	12·0	7000	1·0	0·84	17·0	4540
1·00	0·84	5·5	3000	1·5	1·07	8·5	4170
1·5	1·07	2·5	2500	1·8	1·22	6·0	3570
1·6	1·13	2·0	2450	2·0	1·30	5·0	3350
2·0	1·30	1·0	1500	2·5	1·50	3·0	2630
For 10 cusecs discharge.				*For 20 cusecs discharge.*			
0·75	0·54	24·0	7000	1·0	0·84	23·0	4540
1·0	0·84	11·5	4500	1·5	1·07	11·5	4170
1·5	1·07	5·5	3600	1·8	1·22	8·0	3700
1·8	1·22	4·0	3300	2·0	1·30	6·5	3350
2·0	1·30	3·0	2700	2·5	1·50	4·0	2700
2·5	1·50	1·5	1700				

Depth of flow in feet.	Velocity in feet per sec.	Bed width in feet.	Bed fall or surface fall for Kutter's $n = 0·0225$ slope 1 in.	Depth of flow in feet.	Velocity in feet per sec.	Bed width in feet.	Bed fall or surface fall for Kutter's $n = 0·0225$ slope 1 in.
	For 25 cusecs discharge.				*For 60 cusecs discharge.*		
1·0	0·84	29·0	4600	2·0	1·90	22·0	5000
1·5	1·07	15·0	4500	2·5	1·50	15·0	4400
2·0	1·30	8·5	3800	2·75	1·60	12·0	4000
2·5	1·50	5·5	3200	3·0	1·70	10·0	3450
2·75	1·60	4·5	2900	3·5	1·87	7·5	3200
3·0	1·70	3·5	2500	4·0	2·04	5·5	2900
	For 30 cusecs discharge.				*For 70 cusecs discharge.*		
1·5	1·07	18·0	5000	2·0	1·30	26·0	5000
2·0	1·30	10·5	4350	2·5	1·50	17·0	4500
2·5	1·50	7·0	3700	2·75	1·60	14·5	4000
2·75	1·60	5·5	3030	3·0	1·70	12·0	3700
3·0	1·70	4·5	2860	3·5	1·87	9·0	3300
				4·0	2·04	6·5	2800
	For 35 cusecs discharge.				*For 80 cusecs discharge.*		
2·0	1·3	12·5	4500	2·5	1·50	20·0	4800
2·5	1·5	8·5	4000	3·0	1·70	14·0	4150
2·75	1·6	7·0	3640	3·5	1·87	10·5	3500
3·0	1·7	5·5	3130	4·0	2·04	8·0	3200
3·5	1·87	3·5	2220	4·5	2·20	6·0	2900
	For 40 cusecs discharge.				*For 90 cusecs discharge.*		
2·0	1·3	14·5	4500	2·5	1·50	23·0	4800
2·5	1·5	9·5	4000	3·0	1·70	16·0	4350
2·75	1·6	8·0	3700	3·5	1·87	12·0	4000
3·0	1·7	6·5	3250	4·0	2·04	9·0	3200
3·5	1·87	4·5	2860	4·5	2·20	7·0	2600
	For 45 cusecs discharge.				*For 100 cusecs discharge.*		
2·0	1·3	16·0	4300	3·0	1·70	18·0	4540
2·5	1·5	11·0	4170	3·5	1·87	13·5	3700
2·75	1·6	9·0	3800	4·0	2·04	10·0	3450
3·0	1·7	7·0	3080	4·5	2·20	8·0	3100
3·5	1·87	5·0	2900				
	For 50 cusecs discharge.						
2·0	1·30	18·0	4800				
2·5	1·50	12·0	4100				
3·0	1·70	8·5	3700				
3·5	1·87	6·0	2900				
4·0	2·04	4·0	2200				

The maximum velocity that will not erode the earth slopes in ordinary soils may be taken to be 3 feet per second. A wide shallow channel is always preferable as in this case the velocity of flow will be much less and thus the channel bed and sides will not get eroded.

Silt in rivers and streams.—" Silt is carried in suspension in the water of a stream or is rolled along the bed. The quantity of silt

suspended in each cubic foot of water is called the 'charge' of silt. The eddies which are constantly thrown off from the bed keep it in suspension." [*Bellasis*, 1931.]

"Silt is at once the bane and blessing of an irrigation engineer. It causes great trouble and sometimes disaster, when it is deposited in canals and distributaries; it is in many cases the secret of the success of an irrigation scheme, where the silt is of the right kind and fertilizes the fields on which it is delivered. Silt varies enormously in nature, and generally consists of sand and mud. Where rivers debouch from hills at a steep slope and have a velocity of 10 to 15 feet per second, boulders, coarse sand and gravel travel with the water and those deposits are harmful if they are carried into irrigation canals from the parent river. In flat alluvial tracts where the velocity of stream flow does not exceed 2 to 3 feet per second, the silt consists of fine sand and particles of fertilizing mud. The silt charge and the quantity of rolling bed silt in any stream vary according to the conditions of the moment." [*Buckley*, 1920].

River and canal sediment may be divided into the following grades distinguished by their mean diameters in millimeters [5 (*c*)]:—

Nature of silt.	Diameter in millimeters.	Nature of silt.	Diameter in millimeters.
Clay	0 to 1/256.	Medium fine sand ..	1/8 to 1/4.
Very fine silt ..	1/256 to 1/128.	Medium sand ..	1/4 to 1/2.
Fine silt	1/128 to 1/64.	Coarse sand	1/2 to 1.
Medium silt	1/64 to 1/32.	Very coarse sand ..	1 to 2.
Coarse silt	1/32 to 1/16.	Gravel	2 to 4.
Very fine sand ..	1/16 to 1/8.		

Observations in the Missouri river showed that all particles below $\frac{1}{16}$ millimeter in diameter were found in suspension along all cross-sections of the river. In the Punjab rivers, this limit has been found to be 1/20 millimeter in diameter.

Siltometers.—Till recently, the only method of grading silt into its various fractions was by Kennedy's apparatus. This apparatus gave only the grade of silt for classification. No idea of the actual size of the silt particles could be got from it.

A simple arrangement, viz., the siltometer designed by Amarnath Puri of the Punjab Irrigation Research Institute is capable of giving the actual diameters of silt particles. The siltometer is based on the principle of grading silt particles by allowing them to fall through a long column of water and collecting the different fractions in separate boxes that move into position under water at predetermined intervals of time. A description of the arrangement and its use and the mathematical calculations for arriving at the correct diameters of silt particles are given in the *Punjab Research Institute Publication, Volume II, No. 7.* There are other types of siltometers also which are more complicated in their design and use.

Transportation of bed silt in flowing water.—In designing channels for carrying runoff with non-erosive velocities for soil erosion control measures a study of the relationship between the nature of the bed material of the channel and the mean velocity of flow of water in the channel will be helpful. Kennedy's observations on irrigation channels which were neither silting nor scouring (regime channels) in the Bari Doab cannal system of the Punjab led him to suggest that the "critical" velocity for a certain grade of silt was a function of the depth of flow. The formula is given as follows:—

$$Vo = Cd^n$$

where, Vo is the mean "critical" velocity in feet per second, i.e., the velocity which would cause neither scouring nor silting; $d =$ the depth of flow, $C =$ a constant depending on the nature of the silt and $n =$ a constant. Kennedy's equation for the Punjab canal is—

$$V = 0{\cdot}84\, d^{0{\cdot}64}$$

Similar studies have been carried out in other parts of India and different equations have been formulated for different rivers. [*Lacey*, 1939.]

The following are a few of them:—

Formula.	Source of data.
1 $V = 0{\cdot}84\, d^{0{\cdot}64}$	.. Derived by Kennedy for the Punjab rivers (sandy silt).
2 $V = 0{\cdot}91\, d^{0{\cdot}57}$	.. G. C. Stawel, Shwebo canal system (fine sand).
3 $V = 0{\cdot}67\, d^{0{\cdot}55}$	.. Godavari Western Delta (fine sand).
4 $V = 0{\cdot}93\, d^{0{\cdot}52}$	.. K stna Western Delta.
5 $V = 0{\cdot}95\, d^{0{\cdot}57}$	.. Derived by Lindley—Lower Chenab canals (standard sand).
6 $V = 0{\cdot}39\, d^{0{\cdot}73}$	.. Derived by Ghaleb, Egyptian canal system. (fine silt).

Thrupp who has investigated the relationship between mean velocity, hydraulic mean depth, and erosive or scouring power of a stream shows that while the scouring power increases with the mean velocity, it decreases with the hydraulic mean depth.

The following information compiled by him is taken from the *Irrigation Pocket Book* by *Buckley* (1920):—

—	There is no scouring in a channel of H.M.D.	Until a mean velocity is reached of.
	FEET.	FEET PER SECOND.
Fine silt	1·0	0·4
	2·5	0·7
	5·0	0·9
	10·0	1·5

—	There is no scouring in a channel of H.M.D.	Until a mean velocity is reached of.
	FEET.	*FEET PER SECOND.*
Heavy silt and fine sand	1·0	0·9
	2·5	1·5
	5·0	1·75
	10·0	2·25
Coarse sand	1·0	1·75
	2·5	2·25
	5·0	3·0
	10·0	3·5
Small pebbles (size of peas) and gravel..	1·0	2·25
	2·25	3·0
	5·00	3·5
	10·00	4·5
Large pebbles (hen's egg size) and coarse gravel.	1·0	5·0
	2·5	6·0
	5·0	7·0
	10·0	9·0

Bellasis (1931) says that " rolling power depends on V and is probably not affected by d, i.e., the depth of flow. For a given value of V and any particular kind of silt there is no doubt a certain limiting depth below the bed down to which movement takes place. There is thus a limiting discharge of rolled material. Scour of the bed may be effected by rolling or by wearing. In either case it depends on V."

" If a stream has power to scour any particular material from its channel it has power to transport it, but the converse is not always true. If a stream is not fully charged it tends to become so by scouring its channel; but except when the material is soft or loose, it has more difficulty in eroding than in transporting it. Earth, especially clay, gravel shingle or boulders may form a very hard channel."

Parker gives the following table for the bottom velocity in a channel which just produces motion in the substances mentioned. [*Buckley*, 1920]:—

Material.	Feet per second.	Material.	Feet per second.
Soft earth	0·25	Gravel and coarse sand ..	1·0
Fine clay	0·25	Pebbles 1 inch in diameter.	2·00
Soft clay	0·50	Pebbles: egg size ..	3 to 3·3
Finest clay	0·60	Stones 3 inch diameter ..	5·0
Fine sand	0·70	Boulders 6 inches to 8 inches in diameter.	6·6
Coarse sand	0·80	Boulders 12 inches to 18 inches in diameter.	10·0

The permissible canal velocities as recommended by *Fortier and Scobey* (American Engineers) are given below. [*University of Iowa Technical Bulletin No.* 5]:—

Original material excavated from canal.	Velocity in feet per second after ageing of canal carrying. Clear water—No detritus.	Water transporting colloidal silts.	Water transporting non-colloidal silt, sands gravel or rock fragment.
Fine sand (non-colloidal)	1·50	2·50	1·50
Alluvial silts when non-colloidal ..	2·00	3·50	2·00
Ordinary firm loam	2·50	3·50	2·25
Fine gravel	2·50	5·00	3·75
Stiff clay (colloidal)	3·75	5·00	3·00
Alluvial silt when colloidal	3·75	5·00	3·00
Coarse gravel (non-colloidal) ..	4·00	6·00	6·50
Cobbles and shingles	5·00	5·50	6·50
Shales and hard pans	6·00	6·00	5·00

"They stated that the determination of permissible velocities was not possible from the data on transporting velocities or mere non-silting velocities. Materials easily transported may be difficult to scour because of the presence of colloidal material, clay or other binding substances or because they become bedded to form a dense lining for the channel. They maintained that velocities calculated on the basis of Kennedy's formula, were too low to be accepted by the American Engineers. They said that 'in soil gradations finer than gravels, it is recognized that resistance to erosion depends on the cohesion between individual particles. For the gravels—fine, coarse and cobbles—the resistance is by virtue of weight, shape and density of units, sided by mechanical obstruction afforded by one unit by its mixture with others. The difference between colloids and colloidal silts should be noted. The first will remain in suspension even if all the velocity is eliminated even for a long period of time.' In column (4) the figures indicate that water conveying abrasive sand or gravel will make some materials more resistant by furnishing the constituents needed for a graded bedding. On the other hand, shales or slick tough clays are themselves resistant and this resistance is reduced when a powerful abrasive is contained in the water." [*University of Iowa Technical Bulletin No. 5.*]

A series of extensive tests [*University of Iowa Technical Bulletin* No. 5] were conducted in the laboratory at the Iowa Institute of Hydraulic Research for studying the relationship between the actual size of the bed material and the bed or bottom velocity required just to move the material. Sand from Iowa river, crushed limestone from a quarry at Iowa, Haydite obtained from Kansas and dune-sand obtained from Iowa were used. For unigranular materials ranging

from $d = 0{\cdot}35$ m.m. to $d = 5{\cdot}7$ m.m. in diameter and for specific gravities $S = 1{\cdot}83$ and $S = 2{\cdot}64$ the velocity in feet per second at a point 0·05 feet above the bottom is given by

$V{\cdot}05 = 0{\cdot}67\, d^{4/9}\, (S-1)^{1/2}$ and the velocity at a point 0·025 feet above the bottom by $V{\cdot}025 = 0{\cdot}58\, d^{4/9}\, (S-1)^{1/2}$ By linear extrapolation the bottom velocity would be—

$V = 1/2\, d^{4/9}\, (S-1)^{1/2}$

It may generally be taken that mean velocity of flow in a stream is 1·3 times the bed velocity. So, from the above relationship, the mean velocity of a channel required just to set the bed material in motion may be found out. Further tests are required to universally establish the above relationship for different diameters of bed materials of different specific gravities.

It may be noted here that the specific gravity of silt in Indian rivers is 2.65 times. [*Lacey*, 1939] that of quartz and the relationship established from Iowa laboratory tests may be applied to the silts in Indian streams without much error.

Diversion ditches.—In the case of lands terraced the waterfall erosion ceases as the water from the terraced fields are diverted to special outlets. If it is considered that no useful purpose will be served by terracing, then the drainage water above the heads of a series of gullies is diverted through a single channel where it can be properly handled. Such catchwater drains at the head of gullies are called diversion ditches.

Diversion ditches should be set back from the gully head by a minimum distance of three times the height of gully overfall. If protected natural outlets are available for disposing of the diversion channel water, construction of special outlets will be unnecessary. If no such natural outlets are available then artificial terrace outlet channels already established may be used. In such a contingency the terrace outlets and channels should be designed to accommodate this extra flow from diversion channels.

Conveyance of runoff through gullies.—Stabilisation of gullies through vegetation is a difficult task when the gullies have to be used for conveying runoff during the time plantations are started. In such cases mechanical measures have to be adopted to prevent washing away of the plantations by large volume of runoff. Such protective measures need be only temporary if the vegetation when once established will be able to take care of the gully.

Where mechanical measures are necessary in gully control then permanent structures such as masonry checkdams, flumes, or earth dams supplemented by vegetation should be provided to convey the runoff over critical portions of the gully.

Gullies cannot be said to have been brought under control unless a satisfactory vegetative cover of trees, brush, vines and grass is established in the valley. Grasses take a long time to grow on poor soil; but when once they take proper hold, they can withstand greater velocities of water and consequently can convey greater volumes of runoff.

Natural re-vegetation.—In some cases severely gullied areas respond to natural re-vegetation, if the areas are protected from cattle. Quite often fencing livestock out of the ravine will be all that is required for establishment of a satisfactory growth of natural vegetation.

Fig. 106.—Ponnachchikulam vari in Pudukkottai State: Showing denuded rocks, bund and dams

(By the courtesy of the Pudukkottai Durbar)

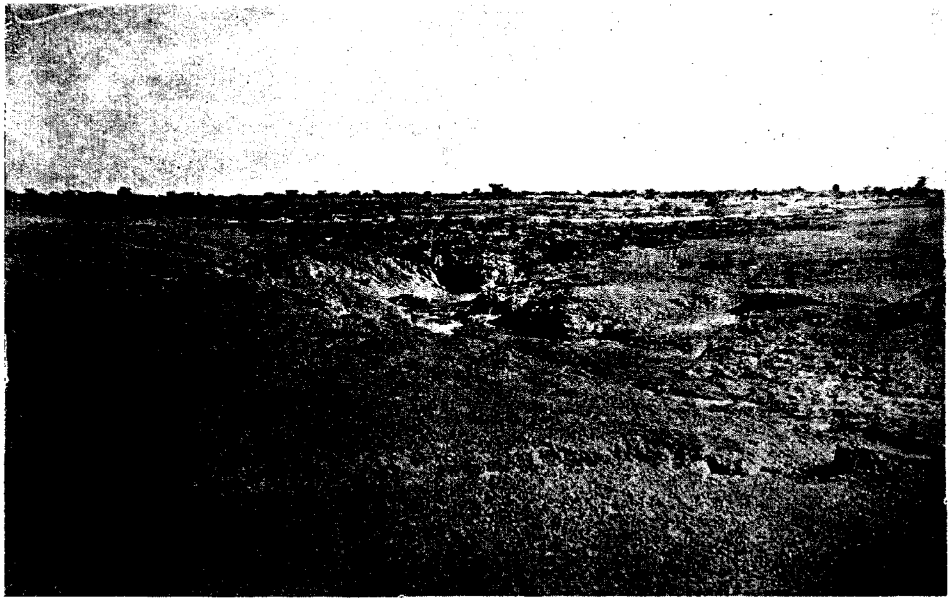


Fig. 107—PONNACHCHIKULAM VARI IN PUDUKKOTTAI STATE: SHOWING GORGES FORMING AND ERODED ROCK

(By the courtesy of the Pudukkottai Durbar)

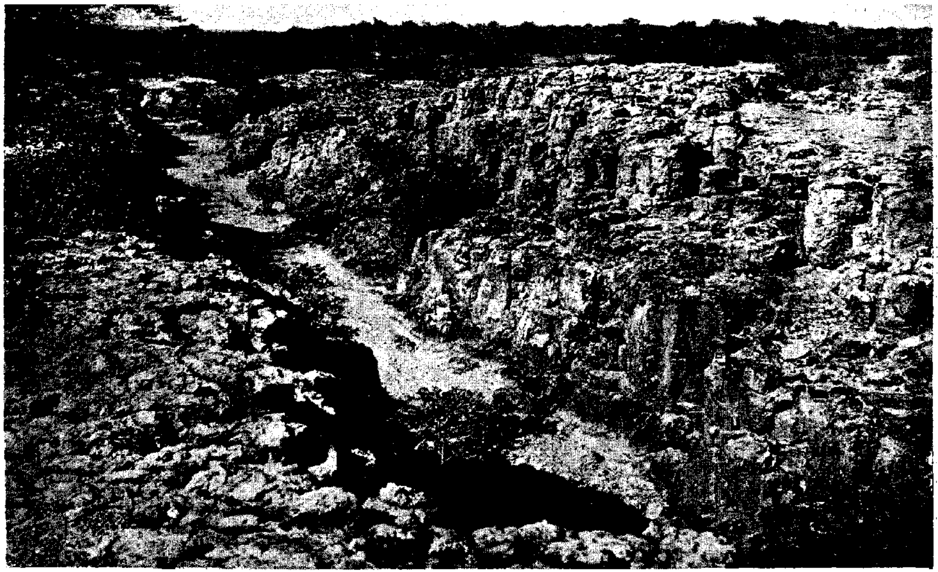


Fig. 108—TUDAYAMPARAI IN PUDUKKOTTAI STATE: GORGE IN CART-TRACK AND DENUDED AND ERODED ROCK.

(By the courtesy of the Pudukkotta Durbar)

Fig. 109—Ariyur vari in Pudukkottai State: Showing denuded land. *See* the slimy deposits in foreground

(By the courtesy of the Pudukkottai Durbar)

CHAPTER XII

CHECK DAMS

Principles governing the use of check dams.—Structures are used in gully control to facilitate vegetative growth. It is seen that the gullies are the result of excessive and unrestricted erosive action of flowing water depending on the nature of the soil met with. The erosive power of running water is proportionate to the velocity of flow which in turn depends on the gradient and the volume of runoff. In check dam control of gullies the erosive velocities are reduced by flattening out the steep uniform gradient of the gully by constructing a series of checks which transform the longitudinal gradient into a series of steps with low risers and long flat treads. Where temporary structures are used they are intended only to function until the vegetation becomes well established to provide necessary protection. Check dams of this type are usually made of brush, wire, poles or loose rock. Substantial checks of masonry, concrete or earth are built where it is necessary to rely upon these alone for permanent control. Temporary check dams thrown across the bed of a gully serve two purposes—

(1) to collect sufficient soil and water to enable the proper growth of vegetative cover, and

(2) to check channel erosion until sufficient stabilizing vegetation can be established at that critical point.

Where the run-off from a drainage area is diverted or held on the watershed or where the gully has reached the dividing watershed then check dams in gully control would be used only for the first purpose. Usually piles of closely compacted rock and brush placed across the bottom of a ravine will collect sufficient soil and water.

Design of check dams.—The most important thing to be considered in the design of a check dam is the capacity of the waterway provided in the dam to pass the maximum discharge without out-flanking the dam ends. The spillway capacities are to be designed for the maximum rainfall intensities that may be expected over a five to ten-year period. In the absence of any rainfall intensity data,

the runoff may be calculated for a rainfall intensity of 2 inches in one hour for small catchments. *Ramser's* rational formula already mentioned may be adopted in the absence of any other formula derived from actual observations to suit the conditions in India.

Notch capacity.—The discharge through a rectangular notch is given by the formula—

$$Q = C L H^{\frac{3}{2}}$$

where, Q = discharge in cubic feet per second,
L = length of notch in feet,
H = depth of water over notch crest in feet,
C = co-efficient depending upon the head of water, length and width of weir crest.

———For practical design the formula, $Q = 3{\cdot}1\ L\ H^{\frac{3}{2}}$ may be used.

The following table gives the discharge over one foot length of spillway for different depths of water over the crest of the notch:—

Depth of flow over crest of notch. H FEET.		Discharge in cusecs over 1 foot length of spillway.	Depth of flow over crest of notch. H FEET.		Discharge in cusecs over 1 foot length of spillway.
0·25	..	0·387	2·00	..	8·767
0·50	..	1·096	2·50	..	12·253
0·75	..	2·013	3·00	..	16·108
1·00	..	3·100	3·50	..	20·298
1·25	..	4·340	4·00	..	24·800
1·50	..	5·695	4·50	..	29·593
1·75	..	7·177	5·00	..	34·659

Height of check dams.—A temporary check dam should rarely have an overfall height of more than 15 inches. *Ayres* (1936) fixed the maximum height as 2·5 feet. In practice it has been found that several low dams are more effective in gully control than one large structure. Low dams are seldom subject to failure and after they silt up and rot away, they can be better protected from overfalls with vegetative cover. For greater heights the static water pressure increases tending to force leaks underneath the structures. Scours due to greater overfall are difficult to control.

Spacing of check dams.—Spacing of check dams is guided by the gradient which for the particular kind of soil met with in the gully gives a non-erosive velocity of flow. The following gradients are generally suitable for all practical purposes:—

For coarse sand with considerable amount of gravel and shingle		About 2 per cent maximum or 1/50.
For fine sand and loamy silt	..	About 1 per cent maximum or 1/100.
Fine lighter soils and clay	..	About 0·5 per cent maximum or 1/200.

Fig. 110—Kummangudi in Pudukkottai State : Sheet erosion

(By the courtesy of the Pudukkottai Durbar)

Fig. 111—MANATURAI VARI IN PUDUKKOTTAI STATE: PALMYRA DAM TO CHECK EROSION

(By the courtesy of the Pudukkottai Durbar)

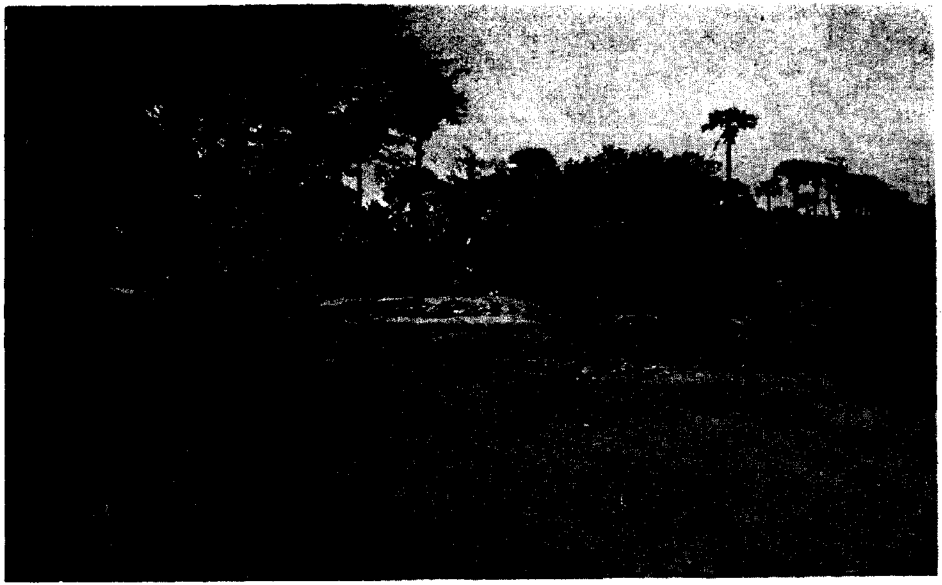


Fig. 112—PONNACHCHIKULAM VARI IN PUDUKKOTTAI STATE: SHOWING DAM AND SILT ACCUMULATION

(By the courtesy of the Pudukkottai Durbar)

Other features of design.—Check dams should be extended far enough into the bottom and sides of the gully to prevent undermining by water forcing through the bottom and ends. Generally an apron of sufficient width and length should be provided to prevent overfall scour. Usually the dam is taken about 1 foot into the bed of the gully and the ends are taken about 2 feet into the stabilized sides of the gully. The notch width should be as wide as practicable to prevent unnecessary contraction of waterway.

Overfall protection.—Waterfall, overfall and gully head erosion refer to the same type of gully extension back into a slope. In gully protection, the upper end where a drop or over-hanging bank is generally found should receive the first attention. Such gully head erosions often extend very rapidly sometimes 50 feet in one season and stable soils in flat slopes stand in danger of being severely cut up if protective measures are not started immediately.

Waterfall erosions at gully heads are protected by sloping the perpendicular sides and sodding them. The overhanging portion is cut and sloped as marked in the dotted line *AB* in the sketch below to a slope of 2 : 1. The scoured portion at the base of the fall is filled with the earth cut from the overhanging portion.

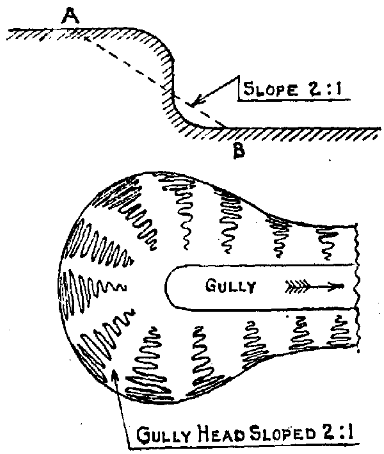


Fig. 113—CONTROL AND ELIMINATION OF GULLIES
Overfall protection.

After the fall has been sloped it is turfed. Suitable grass-legume mixture is sown over the exposed surface. Rye-grass is found to be best suited for such purposes as it grows very rapidly. These localities should be closed to livestock.

Flumes.—Another way of protecting waterfall erosion is to cut back the earth to a slope of 30 degrees or 40 degrees and sides smoothed and channel lined with tough sod or paved with rubble masonry or concrete reinforced with rabit wire-netting. Such structures are called flumes or chutes. On the upper side guide banks of earth or masonry of sufficient length should be constructed to divert all the water into the paved channel. There should be sufficient protection at the toe of the flumes to prevent scouring. Otherwise high velocities created at the toe on account of the waterfall will erode the channel bed and undermine the structure. Turfed chutes may be used for small catchments and masonry chutes for bigger catchments.

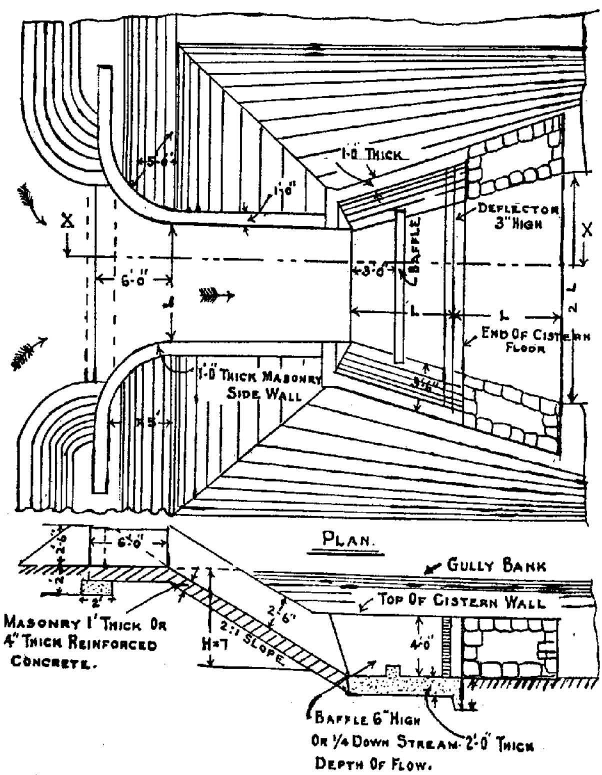


Fig. 114—Design for a masonry flume

For design details of flumes please refer to Publication No. 10 of the Central Board of Irrigation, India, Appendix V.

The best way of curing head overfall next to diverting the flow is to construct a permanent watertight structure of stone or concrete masonry just below the head bank and depend on it for holding soil that is washed above it. Such dams are recommended up to a height of 12 feet.

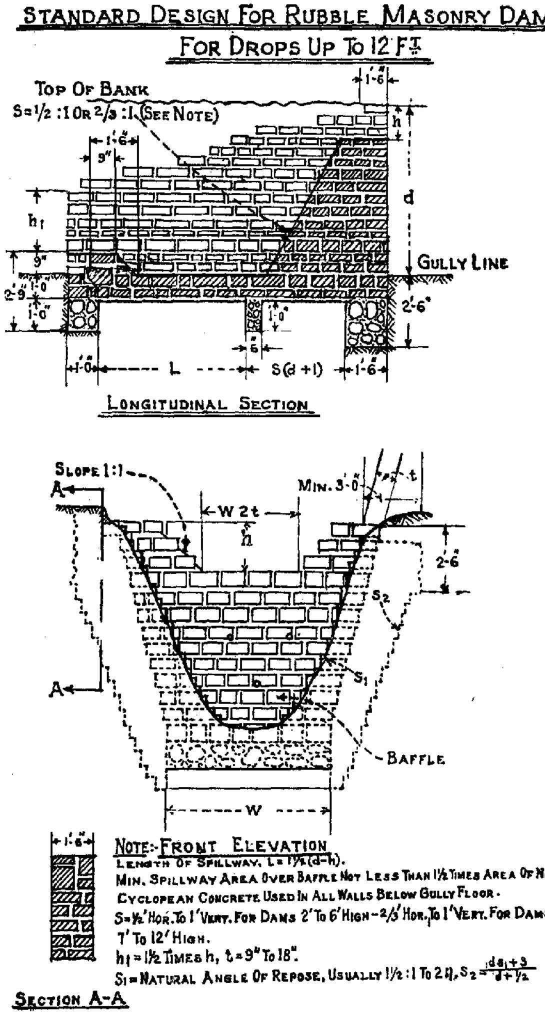


Fig. 115.—STANDARD DESIGN FOR A RUBBLE MASONRY DAM.

Temporary and semi-permanent check dams.—Check dams are usually built of cheap temporary materials such as brush poles and loose stones and are adopted for controlling runoff in small and medium sized gullies where permanent protection is sought by stabilized vegetative cover. They are distinguished from permanent "soil saving" dams which are usually erected in gullies with large contributing watersheds and in gullies that must be retained as permanent waterways. Temporary dams do hold a certain amount of soil for vegetation to take a foothold and to that extent they are called "soil savers." Gullies stabilized with vegetation should be closed to livestock. Otherwise what has been gained by check dams will be irretrievably lost as soon as the temporary checks perish.

Brush dams.—In small gullies 4 to 7 feet in depth check dams are usually constructed with brush and hay. Construction of such dams does not require any skilled labour and the farmer can make use of materials that are available in his farm. They are inexpensive and can be repaired with materials available at site.

Constructing the one-row post or single-row post brush dam.—One-row post brush dam consists of a single-row of country wood stakes to which are tied long branches of trees laid lengthwise of the gully with their butt-ends facing upstream. The longest branches are laid first and progressively shorter lengths on top till the required height is obtained. Before the dam is begun the sides of the gully at the dam site is sloped to 1 : 1 and the gully bottom for the whole length of the dam lowered by 6 inches. The 6 inches excavation is carried up into the bank as high as required to give the necessary notch capacity for discharging the runoff. Then country wood stakes about 3 inches in diameter are driven 2 feet apart along the dam line. The stakes should go not less than 3 feet into gully bed and their tops are kept at such heights as to form a distinct depression in the middle to form a notch of the required waterway to enable the maximum runoff being discharged without undermining the dam at the ends. First wet straw is placed at the bottom and over it longest branches specially selected are laid lengthwise of the gully and well pressed. Over this another layer of straw is spread and shorter branches laid. This process is repeated till a dam of required height at the gully bed is obtained. The brush is anchored on to the stakes by means of galvanized iron wire so that it may not be washed away. Intermediate stakes of shorter lengths are driven and the brush anchored on to them as shown in the sketch to prevent its being lifted from the bed by water. The longer branches act as an apron for the dam and prevent overfall scour. As the green leaves rot, the branches get loose and the dam cannot be kept rigid.

This is overcome by the use of additional rows of stakes as shown in the figure. These stakes can be driven down to take up the slacL wherever it is found necessary.

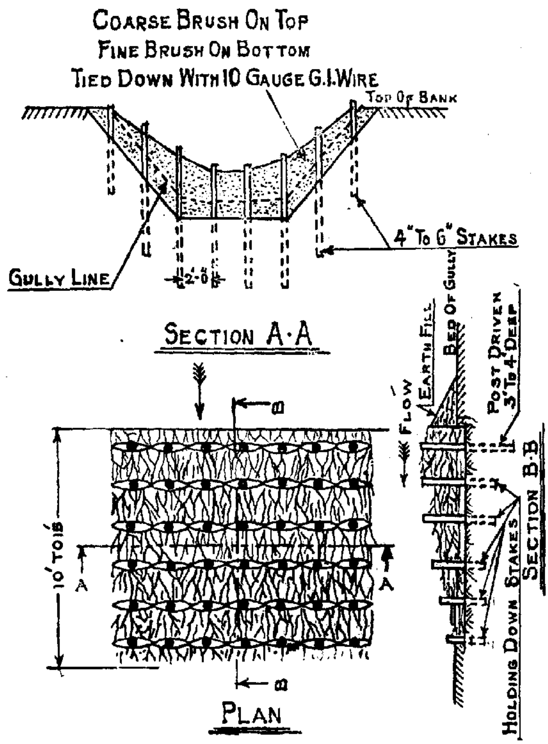


Fig. 116—Sketch of a single-row post brush dam

Constructing two-row or double-row post brush dam.—Two-row post brush dams are used in the control of gullies 7 to 8 feet deep and 20 feet wide which have contributory watershed of 100 acres and more. The construction of the dam is very much the same as the single-row post excepting that in the case of two-row post type the straw and brushwood is laid across the gully between two rows of country wood posts, the distance between the rows being not more than 3 feet. The stakes are 4 to 5 inches in diameter and are driven 3 feet apart to go at least 3 to 4 feet into the hard bed of the gully. A brushwood apron held by galvanized iron wire is necessary to

prevent scour. The double-post type is more efficient and better controlled.

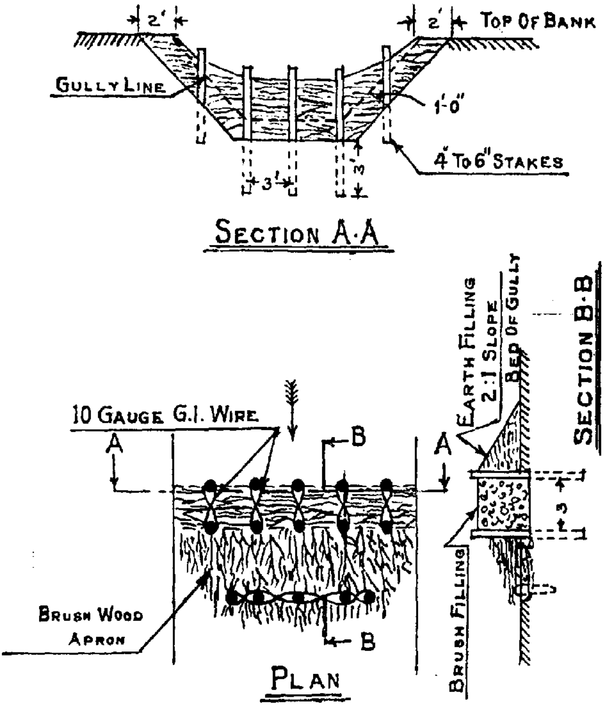
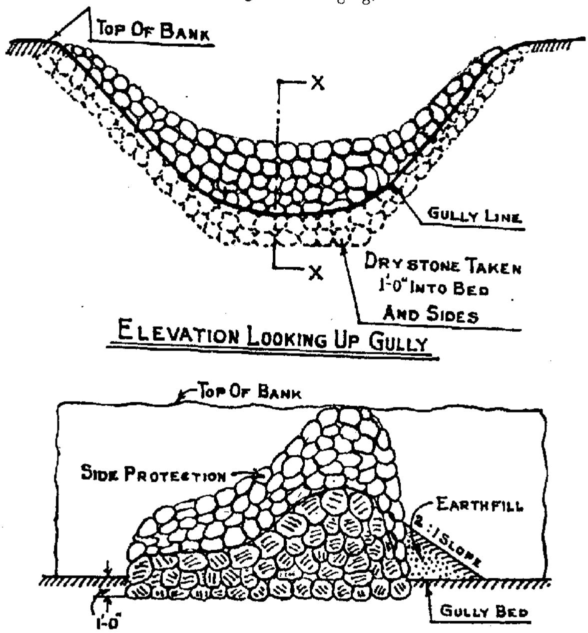


Fig. 117—SKETCH OF A DOUBLE-ROW POST BRUSH DAM

Semi-permanent dams.—Semi-permanent dams that are described below have a longer life and usually do not require any maintenance. They do not require the assistance of vegetative growth for controlling the gully. They are more expensive and can be erected in places where materials are available in large quantities.

Loose rock dam.—If loose stones of fairly good size are available in large quantities very near the gully they can be used for forming check dams. The site where the dam is to be erected is cleared and the sides sloped to 1 : 1. The bed of the gully is excavated to an uniform depth of 1 foot and dry stones packed from that level as shown in the sketch. In the centre of the dam portion sufficient waterway is allowed to discharge the maximum runoff from the

catchment. The stone filling should go at 1 foot to 2 feet into the stable portion of the gully side to prevent end cutting. In rear sufficient length and width of apron has to be provided to prevent scour. The thickness of the apron packing should not be less than 1 foot 6 inches and the gully sides above the apron have to be protected with stone pitching to a height of at least 1 foot above the anticipated maximum water level to prevent side scours being formed by the falling water. Care should be taken to place bigger sized stones on top to prevent their being displaced or carried away by the current. The American practice is to hold down this dry stone fill with woven wire netting. It is not usual to do so in this country, but stability is secured by using stones as large as can be procured and careful packing, bedding and wedging.



SECTION X—X.

Fig. 118—SKETCH OF A DRY LOOSE STONE DAM WITH PICKED BOULDERS

These dams are very effective in steep gullies traversing hilly and mountainous regions. They are also useful in ravines where passage for livestock has to be provided for.

Log dams.—Where timber is plentiful and semi-skilled labour available log dams may be erected for gully control. But the method

is so wasteful of material and labour that it is not practised to any great extent. Figure below gives the details of construction.

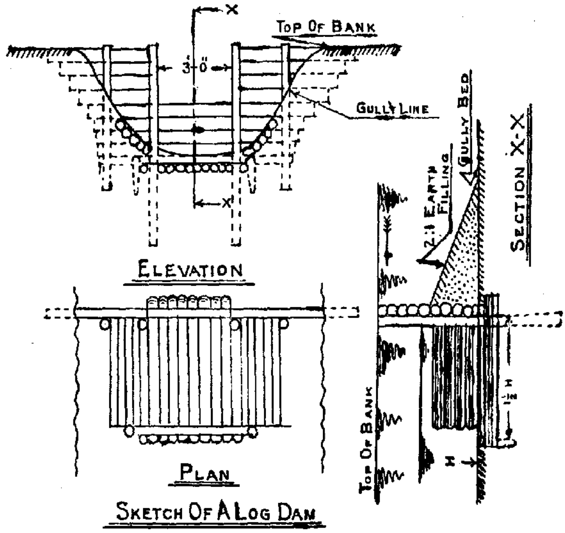


Fig. 119—SKETCH OF A LOG DAM

Rough stone dry packed dams.—Where good building stones of durable quality can be quarried in sufficiently large quantities *pucca* dams of random rubble dry packed can be constructed at a cheap cost. The stones should however be dressed and properly set in with wedges and chips. The bottom of dam should be taken to firm earth at least 2 feet below the bed of the gully. The other particulars of design can be understood from Fig. 120.

Use of check dams in preventing silting up of irrigation tanks.—In the Madras Presidency, extensive areas of wet lands are being irrigated from water stored in tanks or reservoirs. These tanks have their independent catchments. In addition, many of them are in groups, such that each tank in the group either receives surplus water from tanks situated above it or it discharges its surplus into lower tanks or does both. The runoff from the independent catchment is collected and led into the tanks through supply or feeder channels. These feeder channels are uncontrolled and during rainy season, they get a substantial quantity of bed and rolling silt from the catchments into the tanks. The annual deposit of such eroded silt in the tank beds gradually diminishes the impounding capacity of the tanks

with the result that a large quantity of water gets surplussed from the tanks to the detriment of the *ayacut* under them. It is therefore

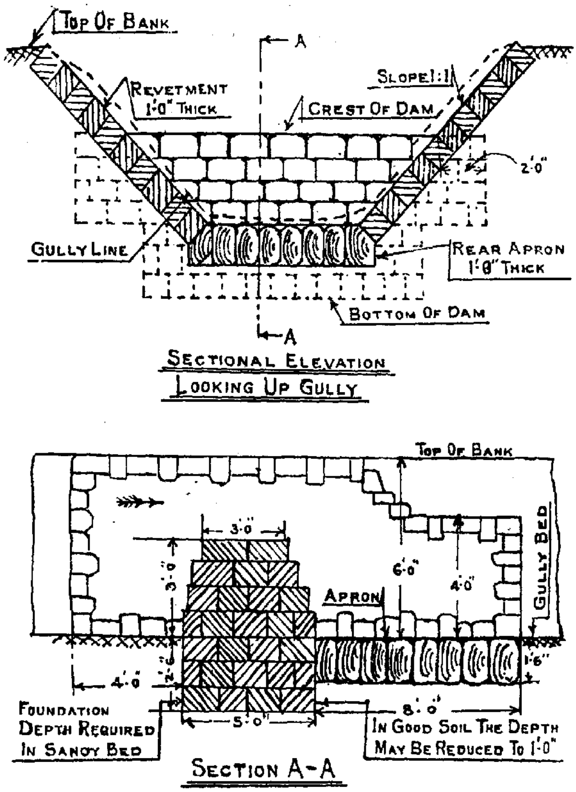


Fig. 120—SKETCH OF A DRY STONE DAM 3 FT. HIGH

essential to prevent tank beds from silting and eventually jeopardizing the irrigation requirements of the *ayacut* under the tanks. Check dams can be efficiently used in preventing silting up of irrigation tanks.

In principle these check dams are a little different from those adopted in gully control. These dams are expected to prevent bed silt from getting into the tank and are porous in construction. They are not expected to hold water and aid in establishing vegetative growth. Single row stake brushwood dams and double row stake brushwood dams may be used with advantage for such purposes. But

it is difficult to maintain these structures during the non-rainy season with the result that silt accumulated at these dams during one rainy season will run down the channel to fill up the tanks, unless the temporary brush dams are properly restored before the next rainy season. Rough stone dry packed dams are the best and they can be constructed without much difficulty and cost. If a series of such check dams are installed at proper places along the whole length of a feeder channel and its tributaries, practically no bed and rolling silt will get into the tank bed. As in the case of gully control, the work should be started in the upper reaches in the first instance and gradually worked down the channels.

It is reported that the Madras Public Works Department have constructed a series of rough stone check dams in the Arni River upper basin in the Ponneri taluk of the Chingleput district along various feeder channels draining into Nagalapuram red tank. The lengths of these dams vary from 15 to 42 feet depending on the width of the channel across which these have been constructed. These dams are 3 feet in height and project 1 foot 6 inches above the beds of the channels. The top width of the dams is 4 feet and the bottom 8 feet. These are reported to be functioning very satisfactorily.

CHAPTER XIII

PERMANENT SOIL SAVING DAMS

A SOIL saving dam is one that is intended to intercept and hold considerable quantities of soil and prevent further erosion within its zone of influence independent of any vegetation. Though such dams have been used in small and medium sized gullies, their principal use is in large gullies which drain large quantities of water from watersheds of considerable size. Sometimes one single dam erected at a critical point in the gully has been very beneficial in lowering the gradient above it to a considerable distance and thus reduce erosion and give a foothold for plant growth which otherwise would have no chance of growing at all.

Permanent soil saving dams should be designed to withstand maximum runoff from the catchment from individual storms that may be expected over a twenty-five year period. But such information of rainfall intensities is not available at present in our province and it will be sufficient if such structures are designed to withstand maximum runoff from the catchment with a two-inch intensity of rainfall in one hour. In the absence of any suitable formula evolved to suit the local conditions, *Ramser's formula* with the necessary co-efficient depending on the size of catchment as already indicated may be adopted.

Spillway crests in masonry dams are usually broad and for calculating discharges over rectangular notches in these cases the accepted formula $Q = 3{\cdot}1\, LH^{\frac{3}{2}}$ may be adopted for all practical purposes. Some engineers prefer a higher co-efficient, but the adoption of 3·1 as a general rule will be on the safe side. [For table of discharges please see notch capacity in check dams already furnished (Chapter XII).]

Rubble masonry dams.—In areas where good stone or rock is available rubble masonry dams are easily constructed. Cement mortar in preference to lime mortar should be used. The foundation of the dam should be taken to impervious strata to prevent failure of the dam due to seepage underneath the structure.

The following empirical rules adopted in the design of irrigation canal drops will be useful in the erosion control dam design. The base width of the weir wall may be $\frac{H + d}{\sqrt{P}}$ where, H is the height of dam to notch crest, d is the maximum depth of water passing over the crest, and P is the specific gravity of masonry which may be taken to be $2\frac{1}{4}$.

Top width a of the crest of the dam may be $a = \frac{3d}{2P}$. The minimum width of notch should not be less than $\frac{7}{8}$ of the average bed width of the gully and should not be more than the full bed width.

The width A of the main apron downstream of the dam should be equal to the width of the notch plus half the maximum depth d of water passing over the crest, subject to a minimum of a bed width of the gully—

$$A = L + \tfrac{1}{2} d$$

Length of the horizontal floor of the drop should be equal to $2d + \sqrt[2]{dh}$ where d is the maximum depth of water passing over the weir and h is the difference of depth of water level above and below weir. If the floor level of drop is kept at the bed level of the gully, then, h may be taken as the height of weir crest from the floor level. The minimum length recommended is $4 + \sqrt{dh}$. The thickness of the masonry apron should be sufficient to resist uplift, and in ordinary soils should not be generally less than $\sqrt{d + h}$. In some cases stilling pools or water cushions for rear aprons are adopted to destroy the energy of falling sheet of water. The usual formula used in Madras Province in irrigation channels for water cushions in cases where the depth of water above and below the drop wall is the same, is as follows:—

Depth of water cushion $= \times = \frac{d}{2} (\sqrt{h} - 2)$;
Where, $d =$ **depth of water ;**
$h =$ **difference in water level above and below dam.**

Provision of water cushions in erosion control dams are not of much importance as the flow of water is variable.

In addition to the solid apron, side revetment should be provided for to protect the sides of gully from erosion due to eddies downstream of the dam. Its length may be equal to 4 $(d + h)$ subject to a minimum of 20 feet from the edge of the solid apron. For at least half of this length the bed of the channel also should be protected with pitching. Before building the revetment the sides should be sloped to 1 : 1 or $1\frac{1}{2}$: 1. The thickness of revetment may be 1 foot built of stone.

Fig. 121—Ponnachchikulam vari in Pudukkottai: Showing dam and terracing

See pool below dam, a breeding ground for mosquitoes. (By the courtesy of the Pudukkottai Durbar)

Fig. 122—STABILIZED GULLY SERVING AS TERRACE OUTLET

The gully was stabilized by means of log check dams

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 123 -OLD HIGHWAY DEVELOPED INTO A TERRACE OUTLET

This satisfactory terrace outlet has a slope of 7 per cent. Note the protection afforded by concrete baffles

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 124 EXAMPLE OF TERRACING IN ORDINARY SLOPING GROUND

(Courtesy of the *Illustrated Weekly of India*, July 2, 1944

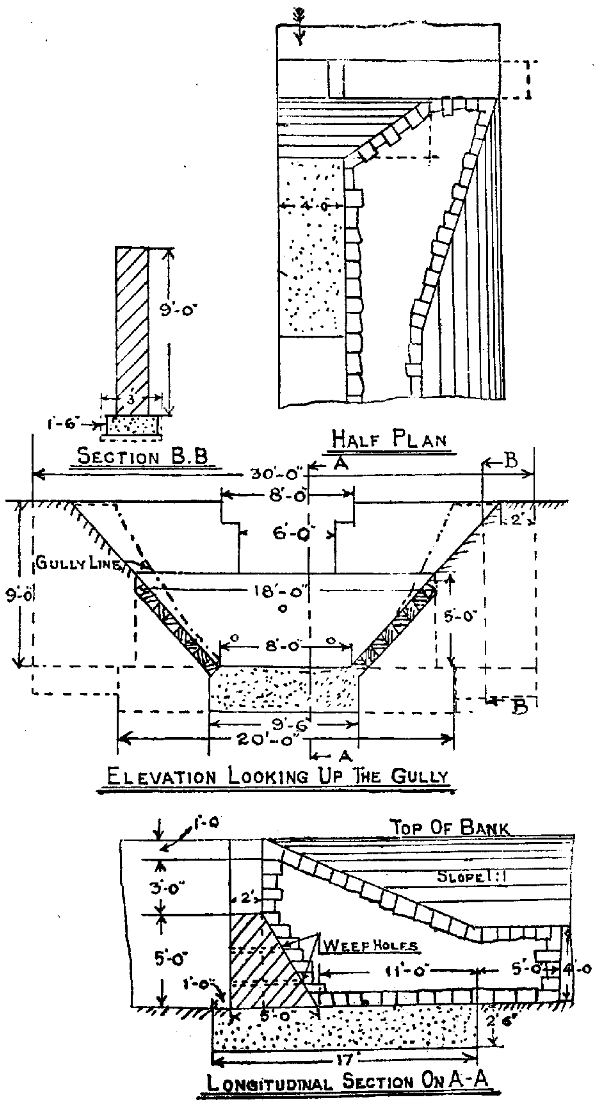


Fig. 1:5—Sketch of a low dam in stone masonry (no cushion)

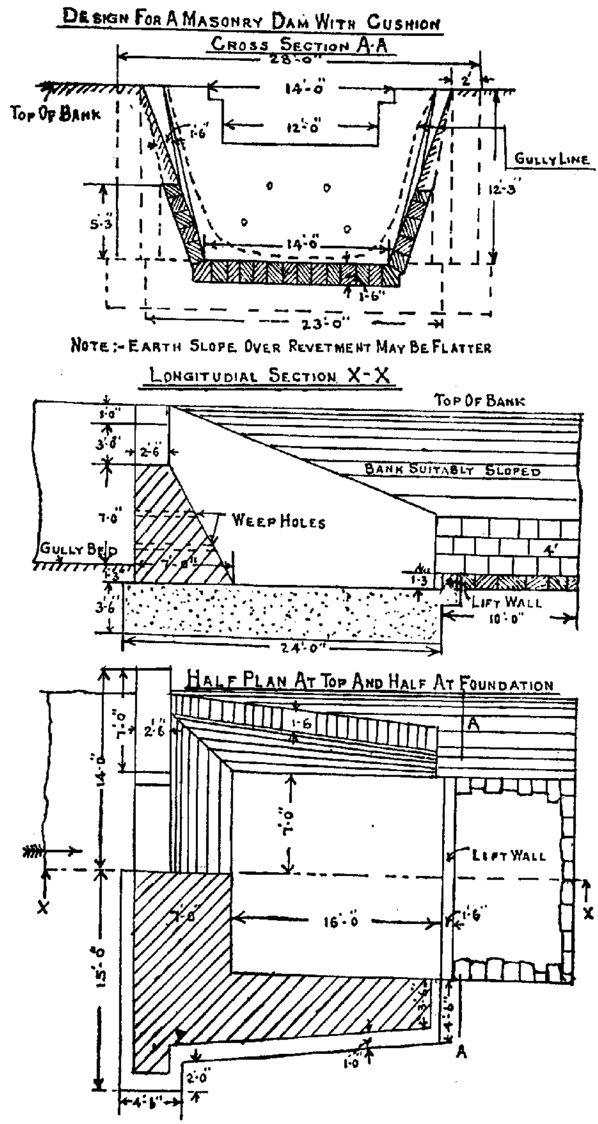

DESIGN FOR A MASONRY DAM WITH CUSHION
CROSS SECTION A-A
28'-0"
14'-0"
2'
12'-0"
1'-6"
TOP OF BANK
GULLY LINE
12'-3"
5'-3"
14'-0"
1'-6"
23'-0"
NOTE:- EARTH SLOPE OVER REVETMENT MAY BE FLATTER
LONGITUDIAL SECTION X-X
TOP OF BANK
1'-0"
3'-8"
2'-6"
BANK SUITABLY SLOPED
7'-0"
WEEP HOLES
GULLY BED
4'
1'-3
LIFT WALL
3'-6"
10'-0"
24'-0"
HALF PLAN AT TOP AND HALF AT FOUNDATION
7'-0"
2'-6"
1'-6
A
14'-0"
7'-0"
LIFT WALL
X
16'-0"
1'-6"
X
15'-0"
7'-0
3'-6"
4'-6"
A
1'-0
2'-0"
4'-6"

Fig. 126

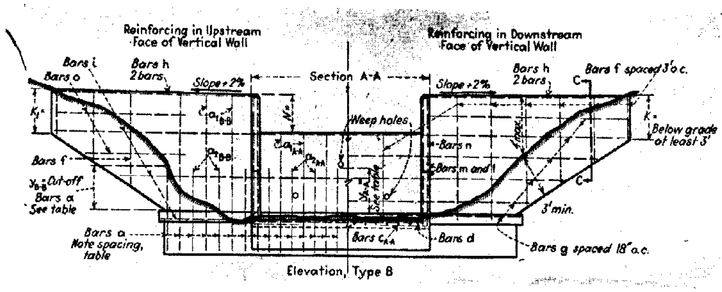


Fig. 127- REINFORCED CONCRETE WEIR NOTCH DAM

Elevation of Type B

(Taken from *Soil Erosion and its Control* by *Q. C. Ayres*)

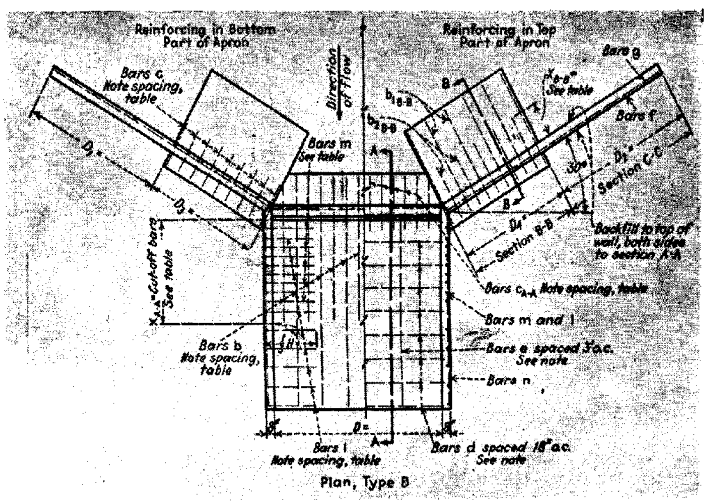


Fig. 128—REINFORCED CONCRETE WEIR NOTCH DAM

Plan of Typo B

(Taken from *Soil Erosion and its Control* by *Q. C. Ayres*)

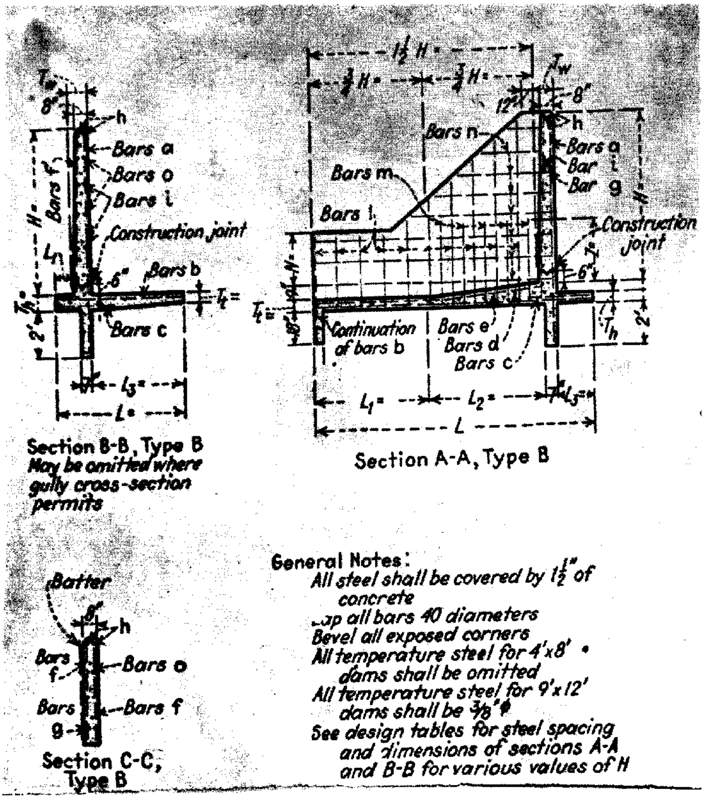


Fig. 129—Reinforced concrete weir notch dam

Various sections of Type B[2]

(Taken from *Soil Erosion and its Control* by *Q. C. Ayres*)

The masonry dam should be properly connected with the stable bank of the gully by means of suitable corewall or wing walls. There is no necessity for any revetment for side slopes above the dam to protect the gully sides. Excavated earth should be well filled in and properly tamped by the side of the masonry bank connections.

Erosion-control structures normally serve variable and unregulated flows that are usually less than the anticipated maximum. Hence they may differ in general proportions and in details of design from similar structures where the normal flow is the maximum and practically constant.

Brick masonry can be substituted in place of rubble masonry if the former is found to be cheaper and if good well-burnt bricks are available within reasonable distance. Concrete also can be used in place of rubble masonry. Reinforced concrete structures can be erected for erosion control in gullies if good technical supervision is available. But where good building stones are available in large quantities, reinforced concrete dams are not recommended as they are very expensive.

Earth dams.—Earth dams in gullies are constructed for the dual purpose of catching and holding soil and for controlling erosion. They are of two types. In one case, the runoff is carried over a paved or natural byewash at the flanks of the dam. In the other, the runoff is carried through a culvert in the dam by means of a masonry drop inlet. In the latter case, it is always preferable to have a byewash arrangement at the flanks to prevent overtopping of the bund due to very excessive runoffs.

In non-malarial localities, these dams serve to hold drinking water for the use of cattle. But, if it is found that the presence of stagnant water is not desirable in the interest of any anti-malarial works, provision has to be made to drain the water.

The best site for an earth dam is the narrowest part of the ravine with high banks where foundation conditions are suitable and where the gradient of the gully below the site is fairly stable. The dam, if constructed at the site, should be able to command a fairly good distance of the gully above it and should submerge one or two gully heads in its waterspread.

The foundation site should be cleared of all shrubs; tree stumps and roots and all the loose top soil removed. The ground should be dug up or ploughed along the length of the bund to form a good joint for the new earth to be laid over it. If the foundation is soft rock, trenches 3 feet in width and 2 feet in depth should be dug at 6 feet intervals along the cross section. Earth for the dam should be removed from projections in the gully bank above the dam.

8

Side spillway dams.—*Ayres* (1936) recommends the use of side spillway dams for gullies carrying runoff from catchments up to 20 acres in extent. If the surface soil at the spillway is hard and can withstand normal velocity of flow, nothing more is needed than to form a defined channel to lead the overflowing water and make it rejoin the ravine at a safe distance below the dam. If the soil at the spillway is not of stable character, then it has to be paved with rough stone to prevent the surplussing water from cutting a deep water course in the saddle. The surplussing capacity of the spillway should be such that the maximum runoff from the catchment should be discharged through the spillway without raising the water level in the pond to 3 feet below the top of the dam.

The usual slopes to be adopted in forming an earthen dam are 1½ : 1 in front and 2 : 1 in rear. A hydraulic gradient line of 1 in 4 drawn across the section of the bund from the water level in front should be completely covered by earth at the rear toe even in the deepest portion of the gully. The top width of the dam should not be less than 4 feet.

In forming the bund, great care should be taken to consolidate the earth in layers of not more than 6 inches thick. All clods should be broken up and if the earth is dry, some water should be sprinkled to make the earth sufficiently moist to enable proper consolidation. Consolidation can be done by means of stone rollers or by allowing teams of cattle to pass over the layer of earth. As the newly formed bank is subject to shrinkage, the height of bank formed should be more than what is required. A shrinkage allowance of one inch for every foot of vertical height of bund is usually allowed in forming new earth dams.

Side spillway dams are not to be constructed in malarial tracts, as it will take some time for the ponds to get filled with earth and in the meantime the stagnant pools will form very good breeding places for malarial mosquitoes.

The following table (*Ellis Irrigation Manual*, page 227) gives the discharge over one running foot of natural byewash for different depths d of flow:—

d = Depth of flow in feet.		Discharge in cusecs per running foot of escape.	d = Depth of flow in feet.		Discharge in cusecs per running foot of escape.
0·25	..	0·292	1·75	..	5·402
0·50	..	0·824	2·00	..	6·599
0·75	..	1·510	2·25	..	7·875
1·00	..	2·333	2·50	..	9·225
1·25	..	3·260	2·75	..	10·641
1·50	..	4·288	3·00	..	12·124

Drop inlet dams.—In drop inlet dams, the runoff water is discharged through a culvert located in the bed of the gully and piercing the dam. The water is admitted into this culvert through a vertical pipe or masonry structure the top of which is kept at the required height to give the desired water level in the pool behind the dam. For small vertical heights, cast iron or stoneware pipes are quite good. For greater heights (above 10 feet), monolithic concrete culverts or a combination of concrete pipe culverts with masonry circular well drops are used.

The pipe or masonry culvert is located in the centre line of the gully. If pipes are used, they are usually laid over concrete 1 foot thick and the invert of the pipe or culvert is kept slightly below the bed of the gully. The vertical inlet pipes are connected with the horizontal pipes by means of suitable elbows or bends. If the inlet chamber is to be of masonry, then it will be constructed over a block of concrete at least 2 feet thick. The bed of the gully and the rear toe of the bund will have to be protected with stone pitching to prevent erosion by the outflowing water which usually has a very high velocity of discharge.

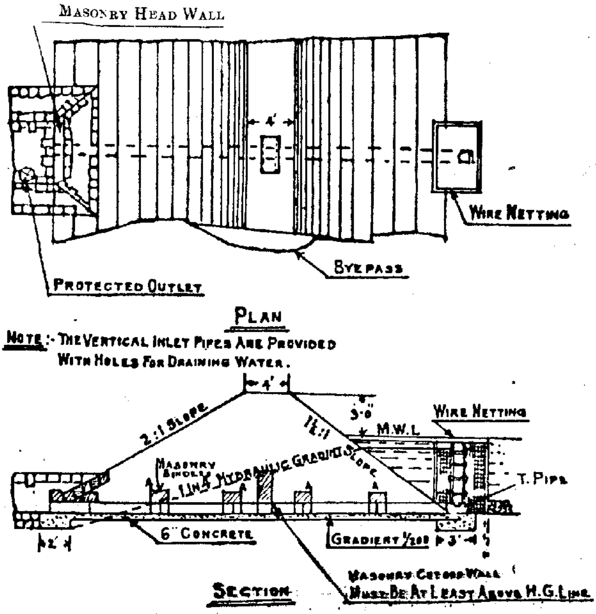


Fig. 130—SKETCH OF A CAST IRON OR STONEWARE PIPE DROP INLET CULVERT IN AN EARTHEN DAM (SOCKET AND SPIGOT JOINTS)

Circular well drops generally used in irrigation canal drops in the Madras Public Works Department can be used for drop inlets. Circular wells are best suited to take up earth pressure due to fill. In the case of drop inlet dams, it is always better to have some side spillway arrangement to safeguard against heavy and unusual runoffs

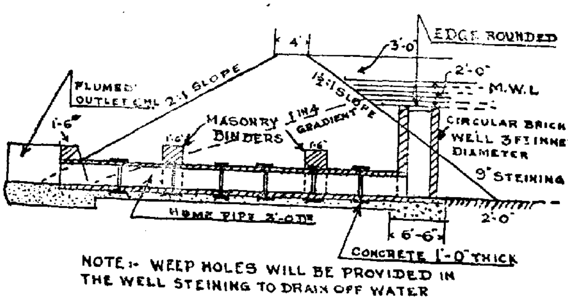


Fig. 131—SKETCH OF A HUME PIPE CULVERT WITH CIRCULAR BRICK WELL DROP INLET

which might overtop the earthen bund and cause damage to property and life in the valley below.

Drop inlet dams are successfully used in malarial tracts in erosion control of gullies. The stagnant pool of water can be drained through the culvert by means of bleeding holes left in the drop masonry or the vertical pipe.

Calculation for diameter of pipe for the culvert.—The maximum runoff from the catchment is computed as for masonry dams. Knowing the quantity of water to be discharged through the culvert, the following formula is used for calculating the size of pipe required.

Unwin's formula for the discharge of a syphon is as follows (*Ellis Irrigation Manual*, page 304):—

$$h = (1 + f_1 + f_2 \frac{L}{R}) \frac{V^2}{2g}$$

where, h = difference in water level above and below the dam (in the case of free flow into air h is the height of water from centre of pipe culvert to maximum water level in the pool behind the dam).

L = Length of the barrel in feet. (This includes the length of vertical pipe also.)

R = Hydraulic mean radius of barrel or pipe (in the case of pipe diameter d; $R = d/4$).

V = Velocity through the barrel or pipe in feet per second.

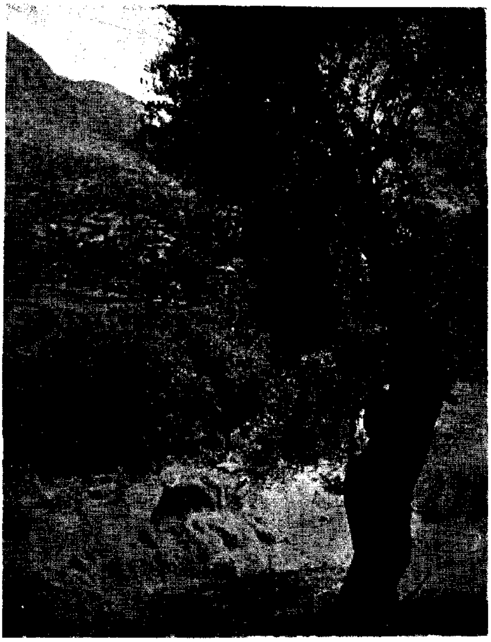


Fig. 132—Olive groves and corn fields characteristic of Cretan hill country

(Courtesy of the *Geographical Magazine* for January 1944)

Fig. 133—Black locusts control erosion

These black locusts were planted for the purpose of healing a bad gully. Rye was used with the locusts for temporary stabilization while the locusts were becoming established

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 134 Kudzu controls gullies in South Carolina

The gully was originally 35 feet deep and 30 feet wide. It is now 20 feet deep and is filling up at the rate of about 3 feet a year

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

f_1 = Coefficient which provides for the loss of head on entry; it may be taken as 0·505 for an unshaped mouth of the same sectional area as the barrel and 0·08 for a bell mouth.

f_2 = A coefficient such that the loss of head by friction through the barrel is $f_2\ L/R \times V^2/2g$.

$f_3 = a\ (1 + b/R)$; and the following table gives the value of a and b.

Nature of surface of pipe or culvert.		a	b
1 Smooth iron pipe	... ...	0·00497	0·084
2 Encrusted iron pipe	... ...	0·00996	0·084
3 Smooth cement plaster	...	0·00316	0·100
4 Ashlar or brick work	... ...	0·00401	0·230
5 Rubble masonry	... ...	0·00507	0·830

If the diameter of the vertical pipe is different from the diameter of the culvert pipe, or in the case of masonry drop inlets combined with pipe culverts, the losses due to friction in the vertical portion and horizontal barrel portion will have to be separately computed to get at a correct discharge.

Drop inlets in existing road culverts.—Many of the culverts in the highways crossing ravines may be used as soil-saving drop inlets at a very little extra cost. By improving such culverts, many of the ravines that are now discharging runoff at uncontrolled erosive velocities can be brought under control and lot of soil that is going to fill up and choke the streams below held up for useful purposes.

CHAPTER XIV

SPECIAL USE OF VEGETATION

In Chapter XI gully formation and its check by means of various works were considered chiefly from the engineering point of view. These works are often expensive and unavoidable. Natural revegetation of gullies is often overlooked as an important and in fact indispensable complementary to such works. It is rarely realised for example that the mere closure of ravine country to all livestock, if necessary by fencing, can often result in natural revegetation within a year or two. All measures of gully control must include revegetation as an essential.

When the soil collapses to form the gully it will usually be found that the angle of fracture is almost vertical. This is considerably above the natural angle of repose of the soil. To leave gully banks in this condition can only lead to further collapse with the next rains. In dealing with gullies, therefore, one of the first operations starting as usual from the highest level or head of the gully is to slope the banks into the bed of the gully until they reach the natural angle of repose. Even where revegetation is easy this is very advisable. At the same time, it is necessary to stabilise the bed of the gully which has still to carry runoff. The stabilization of the bed of the gully is done by first reducing the flow into it by diversion channels above its head. Following this, check dams of some form or other must be constructed. Here, it must be remembered that dams of masonry, woodwork and the like cost money. Where gully gradients are small, it is often sufficient to put in temporary dams to check and collect enough soil to ensure revegetation, which in itself, will stabilize the gully bed. The simplest form of such temporary checks is lines of grass turf bunds across the gully at intervals of about 6 feet. The lines should extend up the bank to about 1 foot above the maximum flood level expected, and may conveniently be backed by any loose stones available. Other checks can be made of wire netting, brushwood, roughstone, etc., reinforced by pegs. The essential is to construct them at frequent intervals and to keep them low, the limit being 15 inches above the bed of the gully and the average 10-12 inches.

Such simple works combined with complete closure against cattle of all kinds will often stabilise a gully with a slight gradient in a very short time by the natural re-growth of grass. In more difficult cases grasses should be introduced either by complete turfing or by sets according to species. The most suitable grasses are those which spread rapidly by stolons such as *Cynodon dactylon* (*hariali*), *Cynodon plectostachyum* (giant star grass), *Amphilophis periusa* and *Pennisetum clandestinum* (*kikiyu*), the last suited to altitudes of 4,000 feet and up only in Madras. Where there is good demand for fodder the giant grasses such as *Pennisetum purpureum* (Elephant or Napier grass), *Panicum maximum* (Guinea grass) and *Panicum antidotale* may be used to fix the silt collected by the check bunds. A favourite creeper also suited to this purpose is *Pueraria thumbergiana* (*kudzu* vine). It is favoured because of its rapid growth, but has the disadvantage of being rather open growing. As yet Madras has little experience of it. Other creepers which have been used in Northern India are *Bignonia radicans* and *Ipomea biloba*.

Once stabilized however, it is advisable to carry revegetation further than mere grass. Trees are therefore introduced. These provide full overhead cover and a valuable humus, while the woods which are formed are a valuable rural asset providing timber and fuel. Little work of this type has been done in Madras, but considerable experience has been gained in the Punjab. Here, the method of introduction is sowing on berms of short lengths of trenches staggered throughout the catchment area as already described in Chapter V. The most promising species for use in dealing with gullies are *Prosopis juliflora*, *Albizzia lebbek*, *Pterocarpus santalinus* (especially in the Ceded Districts), *Pongamia glabra* (especially along the bed margins), bamboos and *Eugenia jambolana*. Where such are raised successfully, a period of about 10 years should see the gully completely under control.

In dealing with gullies with steep gradients, temporary bunds are not effective and the bed of the gully must be stabilized by more permanent structures such as those described in Chapter XII. In revegetation however the same principles apply.

Under Indian conditions, it has to be remembered that gully control is largely concentrated in the dry districts. Where the ultimate intention is to proceed by way of stabilized grass land to afforestation, the introduction of tree species requires careful technical supervision by trained men. Unless the right operation is done at the right time, the result will be failure. Properly afforested and correctly protected, a gully can be transformed from a useless scar on the landscape to a revenue yielding unit and one that will regenerate itself naturally without further expense.

CHAPTER XV

CONTROL OF STREAM AND RIVER BANK EROSIONS

ALL RIVERS that traverse alluvial plains have a tendency to erode their margins especially at bends. In India there are no statistics giving the annual land losses by erosion in the important rivers. But the following information gives a fair idea of the threat to various towns due to erosion along the various important rivers in India [5 (*b*)]. In Bengal, notable towns threatened by river erosion are: Kalna, Katwa and Jaiganj on the Bhagirathi; Khulna on the Bairab; Madaripur on the Areal Khan; Noakhalli on the Meghna; Serajganj and Sarishabari on the Brahmaputra; Rajashabi and Lalgolaghat on the Ganges-Padma; and Kurigram on the Dharla. Some years ago, the Hooghly began to erode the left bank at Diamond Harbour. Certain Government buildings, a railway station and other important structures including the Hardinge Bridge across the Ganges were threatened. In Orissa the Cuttack town which lies at the bifurcation of the Mahanadhi from the Central Provinces and Berar is in some peril due to scour of the river banks. The town of Pilibhit on the bank of the Deoha river has been attacked by erosion. The railway bridges across the Indus at Sukkur and Kotri as well as the Barrage at Sukkur are protected against erosion by river training works. Many towns along the Indus in the Punjab and Sind are attacked by marginal erosions. The serious erosions on the left bank of the Godavari river below the railway bridge has been a source of danger to Rajahmundry town and Dowlaishwaram anicut.

In the Madras Province the threat of erosion in major rivers is to flood embankments which protect valuable agricultural lands. All important villages and towns are located outside the flood embankments and are not liable to danger from erosion. In minor streams and rivers that have no flood banks, erosion of margins is common during floods and much valuable land has been lost due to the uncontrolled erosive activities of these streams.

It is estimated that along that part of the Missisippi river from Cairo, Ill., to Donaldsonville, La., a midstream distance of 885 miles and 921 miles following the caving banks, the annual land loss due

to caving banks is 1,003,579 cubic yards. This works out to a total volume amounting to 10 square miles 86 feet deep. [*Ayres*, 1936.]

An idea of the devastating influence of erosion in stream banks in lessening the extent of useful land may be gathered from the following information regarding the acreage under *Cho* beds at three successive settlements in the Hoshiarpur district in the Punjab. [*Imperial Bureau of Soil Science Technical Communication No.* 36, page 35.]

	Year. 1852.	1884.	1897
Acres of *Cho* land ..	48,206	80,057	94,326

In India, stream and river bank protections are generally undertaken only when the situation demands absolute necessity for such protective works in the interest of valuable lands or towns that are threatened by erosion. In many cases, protection has to be abandoned on account of the excessive cost of such works. Mr. D. N. Sen Gupta, Executive Engineer, Bengal, in his note on *Tortuosity of Rivers and their Training by means of Embankments* published in the *Central Board of Irrigation India Publication No.* 11 mentions the two following instances to illustrate this aspect of river bank protection in Bengal. The town of Serajganj situated on the banks of the Jumna (Brahmaputra) was threatened with complete obliteration and a part of the city was actually carried away by the vagaries of the powerful river, when the town was saved by executing suitable bank protective works and arresting erosion altogether. But the town of Noakhalli situated on the Meghna estuary has practically disappeared as no attempt was made for protection owing to the cost involved being prohibitive and not commensurate with the value of the property to be protected.

River and stream bank protection may generally be classified under the following types:—

(1) Structures that divert the current from directly attacking the bank and aid in the formation of accretions by the side of the structures and at the toe of the bank in the river bed by reducing the velocity of stream in that reach. Such structures are called "spurs" —or "groynes."

(2) Sructures that cover the exposed surface and by their hard nature or otherwise hold the soil and prevent further erosion. Stone and concrete revetments, brushwood or *nanal* roller revetments, subsiding aprons, and flexible mattresses come under this class of work.

Spurs.—Spurs may be further classified as "permeable" and impermeable." There are many forms of permeable spurs, such as tree spurs, pile and fascine spurs, Brownlow weeds, bushing and

brushwood edging. All these act by checking the velocity of the current in a greater or lesser degree according to their nature, and partially diverting its direction. In case operations are perfectly successful, the check to velocity induces silt deposits generally below and above the spurs which in due course get buried under such newly formed deposits. This however is rarely the case with large rivers. It is necessary to influence large rivers with sandy beds to confine their courses within predetermined boundaries and permanent works are necessary for this purpose.

The nature of any form of temporary spur will depend on the nature of bed and the effect it is desired to obtain. It would be absurd to put piles into the bed of a river liable to 40 feet scour or trees in a boulder torrent capable of sweeping away a section of a forest. It is also very necessary to select the kind of the temporary spur taking into account the materials that can be procured economically in the locality.

Tree spurs.—In constructing a tree spur, a single line of small trees is generally put across the stream; but this kind of spur is not of much use. A tree spur to be effective should be able to divert at least 75 per cent of the total volume of water. It is very expensive and troublesome to erect such a tree spur. The work requires special training and equipment, and is not undertaken in the Madras Province. These tree groynes have been used with success in Sind and in Bihar where they have been found effective in removing the main stream from the point of erosion.

Bushing.—Erosion in sandy and easily friable soils of stream banks are stopped by " bushing." The object is to cause a berm to be formed. Large leafy branches of trees are cut and hung from pegs by means of ropes as shown in Fig. 135.

They must be closely packed so as not to shake. At first, they require some looking after; but silt rapidly deposits and the branches become fixed and no longer dependent on rope. If the work is carefully done the result is a smooth regular tenacious berm as shown in the dotted line. If the increase in width due to erosion is too great to be met by bushing from the bank, it is usual to construct a longitudinal line of stakes as shown and attach the bushing to them. The stakes may be 5 feet apart.

In small channels, the spacing of such retards is the same as the width of the channel. This is suited for channels up to 100 feet wide, moderately deep and with mild velocities.

Pile and fascine spurs.—Pile spurs generally consist of two rows of piles, the space between the rows being filled with brushwood which is held down by means of proper cross ties. These serve to check the

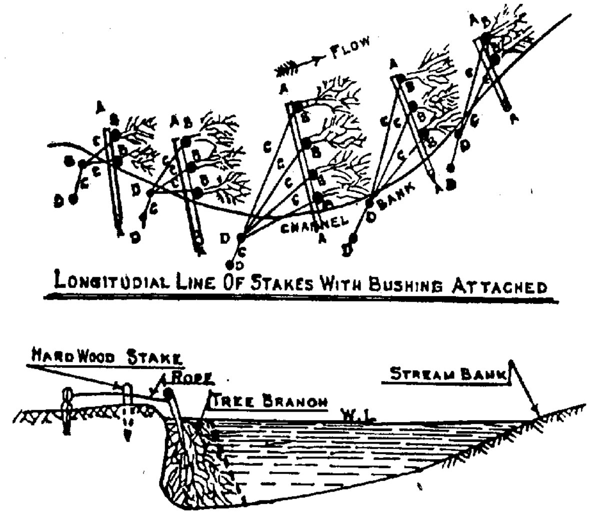


Fig. 135—STREAM BANK PROTECTION WITH "BUSHING"

AAA Waling. CCC Wire tied back or string rope.
BBB Stakes into ground. DDD Strong pegs driven 3 to 6 ft. into ground.

flow of the current and cause silt deposit. The piles which are usually of casuarina, split palmyras or good bamboos are driven into ground along the alignment at intervals of not more than 3 feet apart, the distance between the rows being limited to 3 feet. The rows of piles above the bed level should be secured together with proper walings nailed on to the piles. The distance between each waling should not exceed 1 foot 6 inches. After the brushwood is filled in between the rows and well pressed, cross ties should be fixed diagonally on top of piles to prevent the washing away of the brushwood.

Pile spurs are suitable for localities in river margins and beds where deep scours are not expected. It is estimated that such a spur will defend seven times its own perpendicular length from the shore, viz., four times its length below and three times above along the course of the river. So in practice for the sake of economy the spurs are constructed at right angles to the bank. But when the velocity is great and the spurs are long, they will not stand if placed at right angles to the direction of the current; but if they are erected in an inclined position they divert the direction of flow and cause scour all along the face of the spur. If the object is to protect the bank it is better to use a greater number of short spurs. The system

should be so arranged that the next spur is put in when the one above it ceases to act. If the object is to deflect the direction of the current to a considerable distance from the shore, long spurs inclined to the direction of the stream may be used. The top of the piles in all cases should be well above the water level so that the surface as well as the under velocity may be checked.

When pile spurs act properly, they collect silt in their vicinity. The brushwood filling filters the silt-laden flood water and causes clay deposit. When once accretion of silt has thus occurred, it is stabilized by planting *nanal* and *neernochi* during dry weather and these take immediate growth and collect further silt deposits during the floods of the next season. Gradually the area gets reclaimed well above normal flood level and the river bank prevented from further erosion.

In small channels and streams and to prevent erosion in the margins of major rivers where the dry weather water level is less than 3 to 4 feet, this kind of protective work is being extensively used in South India. It is usual to connect the noses of all the spurs in a system with a double row of pile edging filled with brushwood. If this is not done, then each individual spur is shaped like a hockey stick with the short arm pointing downstream. This type of spur is

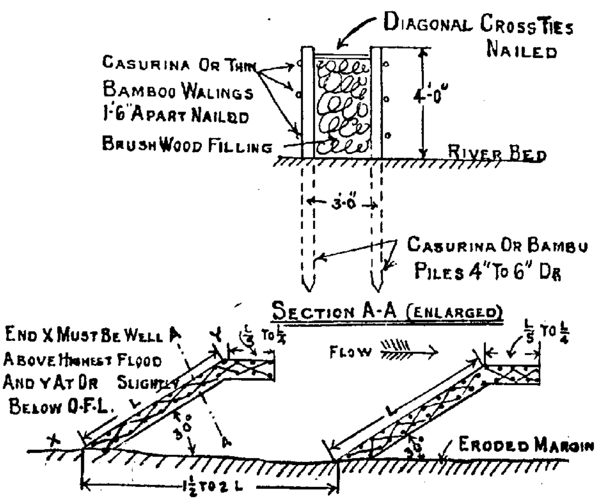


Fig. 136—Sketch of hockey stick type brush wood groynes

Fig. 137—NAGULLANKA SET

Photo of the slips between miles 2/1 and 2/3 in the first week of June 1944

Fig. 138—NAGULLANKA SET

Photo taken from river opposite mile 2/3 of the flood bank looking up the river

Fig. 139 -Model of river Beas looking downstream, showing experimental spurs in action in model studies in the Punjab Research Institute

(Taken from the *Central Board of Irrigation Publication No. 29*)

Fig 140 River Beas Erosion of the left bank

(Taken from the *Central Board of Irrigation Publication No. 29*)

called "Burma Spur." These hockey stick spurs are usually executed at an inclination of 30 degrees to the axis of the river. In very wide rivers like the Godavari and the Kistna, pile spurs are not used as they have no influence whatsoever on the river current.

Brownlow weeds.—The object of this floating spur is to imitate the action of weeds in flowing water for checking its velocity and to bring about the deposit of silt in any channel that is desired to be closed. The advantage of this system is that the velocity of the stream is retarded but not totally obstructed as in the case of pile groynes. Silt is deposited in the river bed at the site of these floating groynes, and consequently the hydraulic mean depth and the velocity of the stream get decreased so that the work helps itself on.

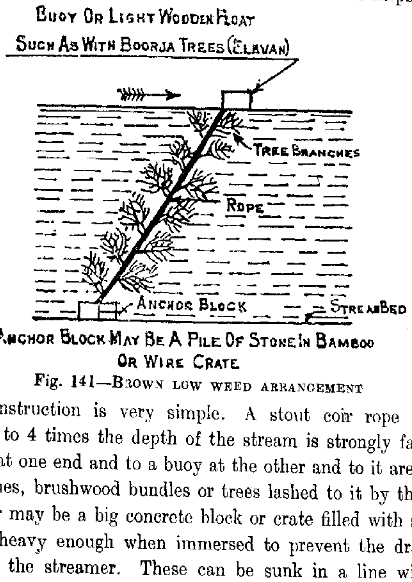


Fig. 141—Brown low weed arrangement

The construction is very simple. A stout coir rope of length equal to 3 to 4 times the depth of the stream is strongly fastened to an anchor at one end and to a buoy at the other and to it are attached tree branches, brushwood bundles or trees lashed to it by their butts. The anchor may be a big concrete block or crate filled with stone and should be heavy enough when immersed to prevent the drag of the current on the streamer. These can be sunk in a line with a fair degree of accuracy from a derrick in the bow of a boat if the depth of water is too deep to prevent laying them by hand.

This method of training or diversion of flood flow is most suitable for channels which require only moderate impediments to divert the current. This method of river training is not now in vogue in the Madras Presidency.

Brushwood edging.—To protect from further erosion, river margins in alluvial soils and sandy beds where bed scour is not deep, brushwood edging work is very well suited. The work consists of two

rows of casuarina or bamboo piles 3 to 4 inches in diameter driven into the bed of the river at 3 feet intervals and rows being kept not more than 3 feet apart. The top of the pile edging which should be level should not project more than 4 to 5 feet above the average bed of the river at site. The length of each pile should be such that at least more than half its length or three feet should be driven into the river bed. The edging should be as nearly parallel to the general axis of the river as possible. The piles in each row should be secured together by means of horizontal walings nailed on to the piles at intervals of not less than 1 foot 6 inches. The space between the pile rows is filled with brushwood and well pressed and securely held in position by means of diagonal cross-ties fixed on the top of piles. The area between the edging and berm is filled with big tree branches or weighted brushwood bundles. The brushwood fill should not be allowed to float away with the current. At the same time the eroded bank slope should be planted with nanal *dubbus.**

During floods, considerable quantities of silt will get accumulated between the margin and the edging. This silt accretion should be planted with *nanal* and *neernochi* as soon as the flood subsides. These plantations take very good growth and prevent the river margin from further erosion. The area can be further stabilized by planting suitable trees. Cattle should not be allowed to trespass and spoil the plantations. [Fig. 142.]

Pile edgings and pile groynes of casuarina trees are found unsuitable in rivers subject to tidal action of the sea as is seen from actual experience in the Coleroon river in the Tanjore district. An important erosion in the Coleroon river at Alakudy about 4 miles from the sea was protected with casuarina pile groynes. It was found that within a year the piles were attacked by sea insects and the pile groynes crumbled to pieces and the protective works became ineffective. The erosion has since been protected with brick masonry revetment on brick masonry block pitching. As building stone is not available within reasonable distance, brick masonry has been used.

Mr. Inglis, Director, Central Irrigation and Hydro-dynamic Research Station, Poona [5 (*d*)] is of opinion that temporary spurs are usually sufficient because when once the river is made to change the course it may not come back for 20 or 30 years. Permanent spurs are undesirable except to hold the river or to pull it across. In either case, careful positioning is necessary relative to the location of the meander of the river. The silt deposit should be planted with ***nanal*** and *neernochi* to prevent further erosion.

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* Clumps of green, stout and well-grown *nanal* with roots.

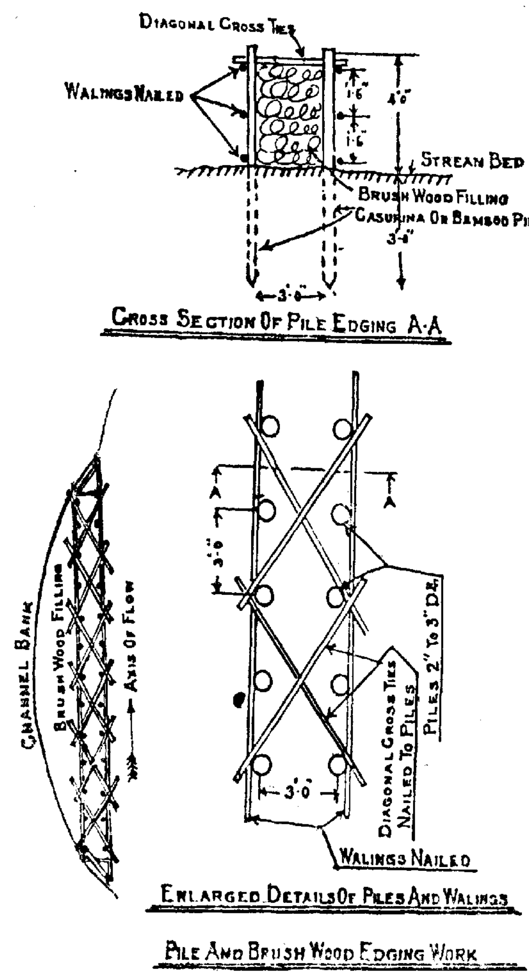


Fig. 142.—PILE AND BRUSHWOOD EDGING WORK

Impermeable spurs or groynes.—A permanent groyne is a sand earth or stone embankment or masonry wall jetting out into the stream, with its head constructed of hard material so designed as to protect itself and the embankment from destructive action. These

works can be built of an infinite variety of designs. The most ordinary kinds of spurs are sand spur, dry stone or boulder spur, the crate or box spur, the masonry spur and the earthcore revetted groyne or "Armoured" groyne. The selection of any particular form for use in any case must depend on the importance of the object to be attained, the material available and the nature of the river.

The action of the spur will be greatly influenced by its direction. A spur perpendicular to the direction of the current will hold up water above it and cause a reflex action below, which if not counteracted may eventually destroy the spur. The reflex action is due to flood water trying to fill up the low level below caused by the obstruction of the spur.

Dr. Uppal [5 (*d*)] of the Punjab Irrigation Research Institute had carried out model experiments with straight hockey stick, reversed hockey stick, and T-headed spurs. Of these, he found that T-headed spurs cause least scour and are therefore being generally adopted in the Punjab. It has been found that in a series of spurs the upstream spur is the most important and this has to be given a curved head upstream like the head of a Bell-bund. If the river is properly trained at that point, the downstream spurs would take care of themselves.

The type of hockey stick spur with curved head pointing up-stream is called Burma type spur and the one with T-head is called fender spur. Mr. Inglis, Director, Hydro-dynamic Research Station, Poona, is of opinion that the former causes more action and is more effective in pulling the river towards it or holding the river at its nose. The fender spur gives protection to the banks and keeps the river smoothly in position.

It has been found by experiments that in the case of T-head or fender spurs, good results are obtained when the ratio $\frac{\text{Distance between the spurs}}{\text{Length of the spur}}$ is between 4 and 5 (vide *Central Board of Irrigation, publication No.* 22, page 14).

The present practice in India in major rivers where costly protective works are to be undertaken to safeguard river embankments and irrigation works is to try different methods of protection on scale models and then execute on the actual site the kind of work that will give the maximum benefit.

The Hydro-dynamic Research Station at Poona and the Irrigation Research Institute at Lahore are conducting such experiments. The results obtained at the experimental stations on the scale models have been actually realized on the actual works in the rivers and many important river training works in the Punjab, Sind and Bengal have been undertaken only on the recommendations of these experimental stations as a result of experiments on scale models.

Fig. 143—VERAHALUR SET IN COLEROON L.B. MILE 27/4-5

Single and double row of casuarina piles with roughstone dump and revetment for protecting the slope of the river margin

(Photo taken on 26th April 1944)

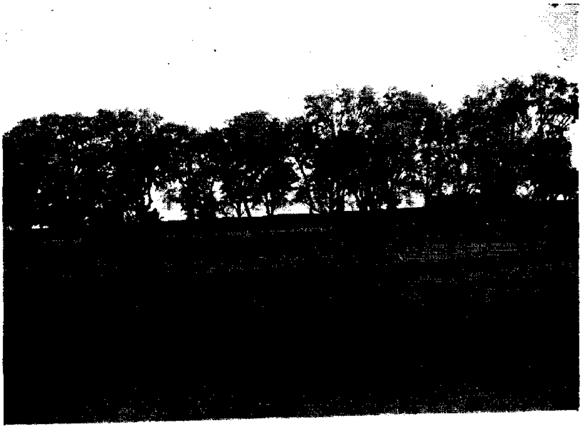


Fig. 144 PHOTO OF ANDANALLUR SET BETWEEN 30/1-2 CAUVERY R.B. SHOWING THE DISTURBED AND SUNKEN BRICK BLOCK REVETMENT

(Photo taken on 3rd May 1944)

Other spurs.—Though sand or earthen spurs unprovided with heads of hard material are of little use as a permanent protection they may often be employed with useful effect in preliminary or subsidiary operations.

The dry boulder spur is used in a similar manner in rivers and torrents near the hills where the velocity is great. When boulders alone cannot stand, crates of various forms made up of rough hewn timber are used to hold a number of boulders together so as to provide more weight than the flood current can move.

Built masonry spurs are possible when the foundation is sound and not liable to erosion. In many river beds deep scours are likely and the spurs should therefore be built on well foundations.

Earth core and stone revetted groynes are commonly used in South India. The core may be of sand and the covering may be of $1\frac{1}{2}$ feet thick stone properly packed. It is usual to have the nose of the groyne constructed of dry stone without any sand filling to withstand scour which is always inevitable at that place. In addition to the solid nature of the nose a sort of subsidising stone apron or berm to a width of 5 to 10 feet and a depth of 2 feet is provided all round the nose and for a short distance along the upstream face at toe level of the covering revetment. The stone protection has a slope of $1\frac{1}{2}:1$ and is taken 2 to 3 feet into the bed of the river. In the Madras Public Works Department the toe of these revetments is further protected by short bamboo or casuarina piles (about 6 feet in length) driven completely into the bed, as shown in the sketch at not more than 2 feet intervals. The groyne is always given a slope from the river margin to the nose. This may vary from 4 to 1, to 5 to 1. The head of the groyne is taken well into the stable soil of the berm and protected from outflanking. If the place where the proposed groyne is to be constructed has a deep summer channel, it is usual to dump

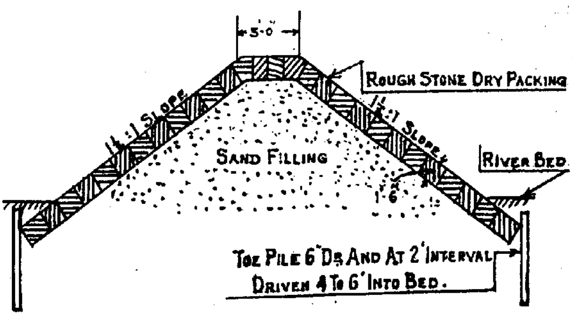


Fig. 145—SECTION OF A SAND CORE REVETTED GROYNE

stones up to summer water level from the base of the groyne and then construct over this dumped stone the earthcore revetted groyne to the required level.

In the Akhanda Cauvery and the Coleroon rivers, this type of groyne has been successfully adopted in diverting the river current from attacking the flood embankments and extensive stretches of land in " sets " reclaimed and planted with *nanal* and *neernochi*.

Plantations and revetments.—For protecting river bank cuttings and marginal erosions in streams with moderate velocity of flow, *nanal* and *neernochi* are being extensively used in South India. The steep eroded bank cutting is eased to a slope of 1:1 or 1½:1 by cutting the overhanging portion and then planted with *nanal* in holes at intervals of 1 foot 6 inches apart. Healthy *nanal* sticks not less than 3 knots and measuring not less than 1 foot 6 inches in length are dibbled in threes for every hole. After the sticks are put in, the holes are properly filled with earth and pressed so that portions below the surface may not be exposed. If the plantations are done as the floods recede they take very good growth and firmly hold the soil and prevent further erosion. When *neernochi* cuttings are planted when the leaves just fall after ripening, they take root quickly and form a good protection against erosion. River beds reclaimed by means of temporary brushwood and pile spurs are stabilized by planting *nanal*. In the Punjab *banka bush* (*Vitex negundo*) and *nara* reed (*Arundo donax*) have been found useful for planting on the banks of *Cho* torrents to save them from further cutting.

In sandy shoals and hard oily clay soils *nanal dubbus* are planted. Clumps of a stout and well grown *nanal* dug up with roots are planted in holes 9 inches in diameter and 1 foot 6 inches deep at suitable intervals and the holes filled up with half a cubic foot of good earth. In salt swamps below H.T.L. sea plants called *thillai* or *alchi* with roots are planted.

Durba or nanal roller or korukkai roller revetments.—Banks newly sloped and filled in from caving are protected by *durba* or *nanal* roller or *korukkai* roller revetments. The following is the method of preparing and forming roller revetment. On level ground 5 stays of double-twisted coir rope sufficiently long to securely tie the rollers should be stretched at intervals of one foot in parallel lines and over this three bundles of *nanal*, grass or *korukkai* 8 inches in diameter should be spread in two layers, the stems being placed differently in the second layer. Over this ½ a cubic foot of fine silt earth should be spread evenly, the whole thing rolled tightly and tied firmly. This constitutes one roller.

Trenches 9 inches wide should be dug on the slopes formed for the revetment and in these trenches the rollers prepared should be laid very closely and staked down with bamboo or country-wood pegs not less than 3 feet long at intervals of not more than 3 feet. This should be properly watered to give good growth.

One disadvantage with this type of work is that *nanal* roots do not get into the natural soil quickly and in the event of a flood during the next season, the rollers are likely to be washed away if the velocity of current is strong. In the Godavari and the Kistna rivers this kind of work is not undertaken now. But in small rivers and other drainage channels this revetment gives fairly good protection and may be used. It is a good protection in an emergency.

Brushwood woven wire fencing fascine work.—This kind of temporary protective work is useful for protecting under cutting of river banks during floods. The following specification for this work is taken from the *Madras Public Works Department Detailed Standard Specification*:—

"Brushwood fascines 1 foot in diameter and 12 feet long shall be prepared with brushwood 20 cubic feet compressed to 10 cubic feet for each fascine and tied securely with twisted coir rope at 1 foot 2 inches intervals. These fascines shall be woven into a fascine mattress by inter-twisting at 3 feet intervals with No. 10 gauge G.I. wires. Brushwood rollers 3 feet diameter and 12 feet long shall now be formed at the end of the strips of fencing wire, which wire shall be woven into a cylindrical casing by tying with loops of No. 10 gauge wire to contain the roller. The filling for the roller shall be 12 cubic feet of sand in bags or 12 cubic feet rough stone as specified encased in 150 cubic feet of brushwood. This wire fencing round the roller shall be securely tied so that the roller can be lowered with the fencing wire and the ties shall support the dead weight of the roller and mattress without any sign of rupture. If the ordinary bamboo rope rollers are used in place of the above they shall be tied securely to the wire fencing mesh.

"The brushwood fascine mattress referred to above shall be securely tied to the wire fencing by wire ties at intervals not more than 3 feet.

"The woven wire fencing mesh with its weighted roller anchor and brushwood mattress covering shall be carefully lowered down the slope to rest lightly against the slope.

"Posts shall now be driven to a depth of not less than 3 feet at 6 feet intervals beyond any cracks on the high margin at places indicated. Three strands of No. 10 gauge wire are to be twisted and carried round the posts and tied securely.

"The ends of the separate units of each mattress shall be well tied to prevent any ends being exposed to the tearing action of the current."

Stone pitching and revetment.—In big rivers like the Godavari and the Kistna, rough stone pitching and revetment form the most important items of permanent protective works. As already said protective works in these rivers are undertaken only when there is an actual threat to the flood banks, on account of the current eroding the river margin to such an extent as to leave practically very little berm on the river side for the flood banks. The lands in rear of the flood banks are low and cultivated with paddy. Any breach in the flood bank would mean extensive damage to crops and the villages situated in the midst of these cultivated lands. In the tidal reaches of these rivers the margins are liable to scour on account of action by waves during heavy winds in the north-east monsoon. Moreover in front of the eroded margins there will always be deep water. Marginal protection with stone revetment can therefore be done only above summer water level. In some cases the depth of summer water at these scoured sites is from 30 to 60 feet. To build this revetment a sort of foundation is obtained by dumping rough stone to summer water level to form a berm 4 to 6 feet in width. In the Tanjore district in the Coleroon river, the apron is formed out of brick blocks built in cement mortar, and the revetment is also of brick masonry in lean cement mortar. In a few cases wells approximately 5 feet square are built and sunk into the bed as a foundation and revetment built above it.

The sketch shows the type of work that is being done in the Godavari river to protect the river margin at important points. The

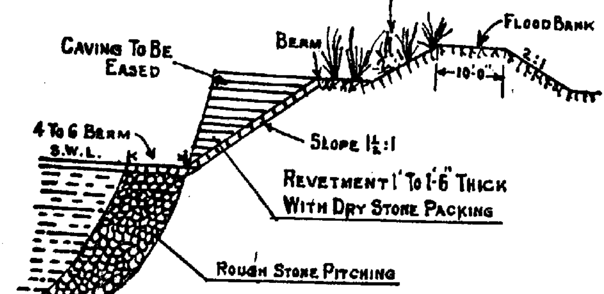


Fig. 146—River bank protection with stone pitching and revetment

rough stone apron will settle down if further scouring takes place and it is replenished whenever necessary. If the revetment gets slightly disturbed on account of the severe current of water during floods, the interstices are planted with *nanal* which by the spreading of its foot gives a very good binding for the soil and revetment.

In small rivers and channels where there is no water during summer such protective works are started on masonry or rough stone dry packed toe walls which are taken at least 3 to 4 feet below the

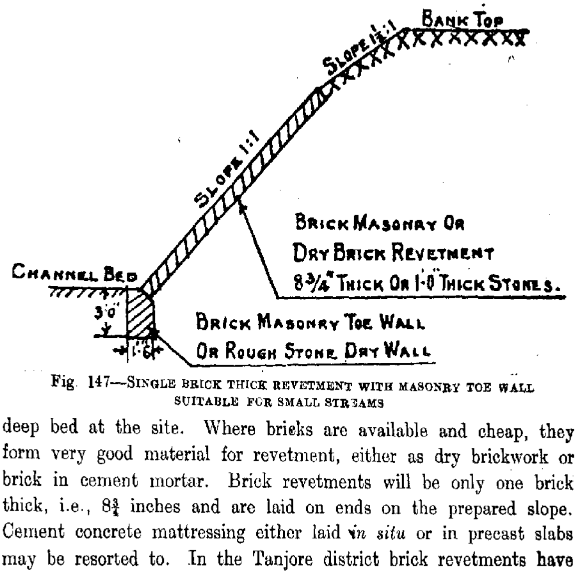


Fig. 147—SINGLE BRICK THICK REVETMENT WITH MASONRY TOE WALL SUITABLE FOR SMALL STREAMS

deep bed at the site. Where bricks are available and cheap, they form very good material for revetment, either as dry brickwork or brick in cement mortar. Brick revetments will be only one brick thick, i.e., 8¾ inches and are laid on ends on the prepared slope. Cement concrete mattressing either laid *in situ* or in precast slabs may be resorted to. In the Tanjore district brick revetments have been extensively used in river bank protection as stones are not available within any reasonable distance. To prevent people removing loose bricks from dry brick revetments, it is usual to set the top 1 foot width in cement mortar. The top of the revetment is usually kept 1 foot above maximum water level. [Fig. 148.]

Whenever a river margin is protected with permanent revetment, it is necessary to plant *nanal* for a certain length immediately above and below the revetment to prevent erosions which are always likely in such circumstances.

It has been found that cement concrete laid in mass *in situ* gives a satisfactory protection against strong waves in exposed portions near the sea. Where waves are strong, mattressing with open joints or

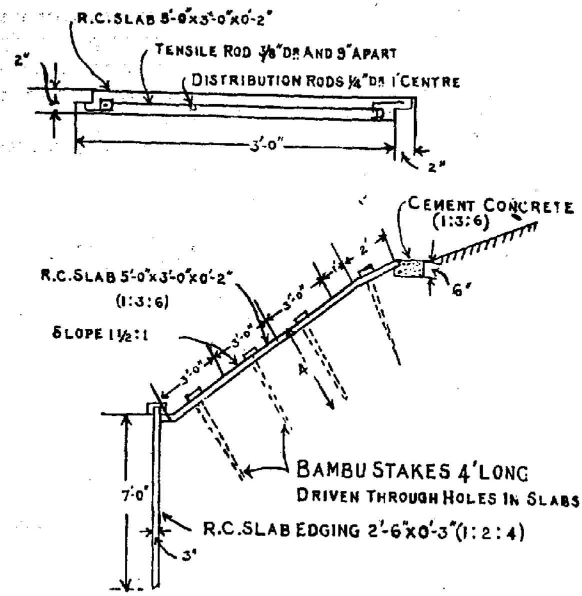


Fig. 148—Precast R.C. slab revetment at Virahalur set in Coleroon river

mere dry stone revetment is often disturbed and the soil below exposed to action by waves. Concrete in hydraulic lime mortar with an admixture of cement laid to a slope of 1½:1 to a thickness of 9 to 12 inches has been found to give satisfactory results near Diamond Harbour, where the river Hooghly is 3 to 12 miles wide and the Bay of Bengal 60 to 80 miles distant [*Lacey*, 1939]. The mattressing is laid over rough stone boulder pitching 2 to 3 feet thick up to low water level.

Another kind of protection used in the United Provinces and Bengal, where scouring channel is deep, is flexible mattressing consisting of specially moulded bricks strung together by galvanized iron wire and anchored to the bank. This flexible mattressing will adjust its position suitably covering all the minor undulations in the eroded margin under water, and thus prevent the place from further erosion. In America [*Ayres*, 1936] on the Missisippi this flexible mattressing is prepared out of reinforced concrete slabs 15 inches × 4 feet × 3 inches and joined together with flexible couplings so that each slab is enabled to move independently of its neighbouring slabs and is thus free to "articulate." Articulation permits close conformity with minor

bank irregularities and assures protection from under cutting. These mattresses are lowered into position by means of special cranes on barges and anchored to the bank. Over these flexible mattressing monolithic concrete pavement is laid to protect the surface above low water level.

Bamboo fencing in Burma.—The following method of training silt-laden hill torrents in Burma where the river is induced to form its own embankment with the aid of bamboo fence is very interesting [*Indian Forester*, Vol. 67, 1941]. All Yoma torrents carry enormous quantities of silt and rubbish during floods. Where these torrents debouch into the plains they have high embankments. The height of these embankments decreases downstream and when the torrents reach the western slope of the Irrawady plain, their banks are over-topped in normal floods and silt deposition on either sides of the torrent takes place. In the lower reaches where the banks are low and get submerged during floods, the stream channel has very little stability and is easily diverted from its course. Bunding with high and low banks were tried without much success. Ultimately bamboo stake fence control was successfully adopted. The work is briefly explained below. The line along which it is desired to form the channel is pegged out. This usually follows a natural depression. All jungle growth to a width of 150 feet on either side of the pegged outline is cut out flush to ground and burnt. For 100 feet on each side of the line simple bamboo stake fences are made with bamboos 5 to 6 feet in length driven into ground at 9 inches intervals with their tops dressed to an average height of about 2 feet above ground level. These posts are lashed to a horizontal bamboo with coir rope about 6 inches below top to hold them in position. The low fences are continued beyond the point which is anticipated to be the limit of silt deposit during the ensuing monsoon season. The fences catch up the many kinds of debris brought down by every flood: This forms a barrier and checks the flow of water and causes silt to be deposited beyond it. In this way every flood serves to increase the silt deposit and thereby heightens the embankments. The channel is not therefore allowed to scour out but is made to deposit its silt evenly along its course and to raise its own bank. Each successive rise further heightens the bank and lessens the overflow and the establishment of banks all along the channel is continued. Along these banks cultivation of paddy has been rendered possible where a few years ago annually inundated scrub jungle was the only growth. Furthermore, this cultivation is permanent and free from danger from floods excepting the highest of the Irrawady floods.

CHAPTER XVI

CONTROL OF WIND EROSION

EROSION BY wind, more often referred to as sand drift or wind drift, has had more publicity than erosion by water, for it is spectacular. An example of wind erosion is the great dust storm of May 1934 in the United States of America, when the sun was virtually eclipsed as it swept from the Great Plains over New York to the sea. While the average man sees nothing wrong in the gradual destruction of the top soil by rain over extensive areas, the sight of driving sand encroaching on cultivated lands immediately raises an outcry. The probable reason is that while the erosion by rain is a slow insidious process, the erosion by wind puts the land out of production within a short period.

In Madras Presidency, while we do not witness the great sand storms occurring in other lands, we can often see wind drift in progress. The heavy thunder showers of April and May can be seen advancing across the plains preceded by a red cloud of dust raised by the cyclonic wind that precedes the rain. During the hot weather " dust devils " can often be seen spiralling their way until they subside. As pointed out in Chapter I sand drift has become a problem over limited areas in Tinnevelly and Bellary districts. The adverse effects of sand drift have also been reported from the dry areas of Kangayam and Dharapuram in Coimbatore district.

The action of wind.—Wind has both ground velocity and turbulence, the latter giving it lifting power. Where the soil is light and devoid of cover, appreciable movements take place by the mere blowing of the soil particles along the surface, while the lighter particles are lifted and carried long distances. Such soil particles while moving have an abrasive action on any obstruction. As the wind loses its velocity the soil particles are deposited and develop into unstable sand dunes or sandy wastes, which lie infertile, only to move with the next heavy wind. It is this phase of wind erosion that has received such publicity. Winds act most spectacularly in arid and semi-arid climates, and cause damage in humid climates also.

Fig. 149—KARUPPUR SET—COLEROON L.B. BETWEEN 89/2—89/7

This shows the soil erosion in the padugai and the washing away of a portion of the existing pile groynes. A "kalagam" has been formed between the padugai and the groynes

(Photo taken on 26th April 1944)

Fig. 150—KARUPPUR SET—COLEROON L.B. BETWEEN MILE 89/2—89/7

This shows the worst erosion of this set as it exists. The front slopes of the flood bank has been eroded and the photo shows the urgent protective works done last year

(Photo taken on 26th April 1944)

Fig. 151—KARUPPUR SET—COLEROON L.B. BETWEEN MILES 89/2–89/7

This shows the revetment along the slope of the bank and the apron works done for the worst erosions caused in 1942. This work is quite successful. The second or the lower apron has silted up slightly and nanal plantation has been done

(Photo taken on 26th April 1944)

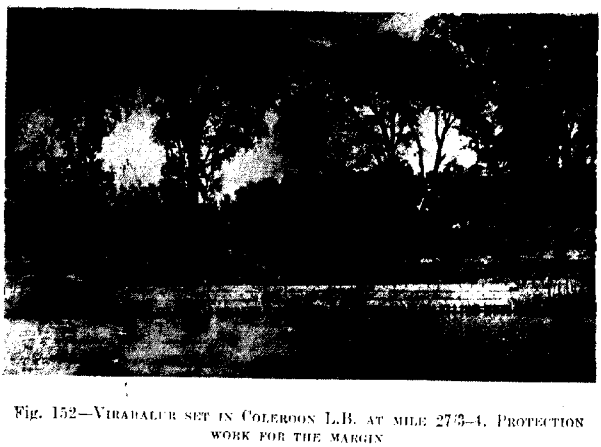


Fig. 152—VIRAHALUR SET IN COLEROON L.B. AT MILE 27/3–4. PROTECTION WORK FOR THE MARGIN

Single row of casuarina piles and stones dumped in bed and R.C. slabs revetted for the slopes and suspended on pegs in front

(Photo taken on 26th April 1946)

Fig. 153—EFFECT OF BLACK LOCUSTS ON GROWTH OF NON-LEGUME TREES

Black locusts at the left. Non-legume trees, 'catalps' at the right. Note the decreasing height of 'catalps' trees with increasing distances from the locusts

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

Fig. 154—VIEW OF ADJACENT PLOTS SHOWING EROSION AND CASUARINA PLANTATION

Fig 155—NEARER VIEW OF AREA PLANTED WITH CASUARINA

Fig. 156—WILLOW WIND-BREAK ON PEAT

This old willow wind-break aids materially in the control of erosion in Western New York

(Taken from *Conservation of the Soil* by *A. F. Gustafson*)

For example, sand drift from the sea-shore inland is a phenomenon that may occur anywhere irrespective of the local climate.

The control of wind erosion.—As with water erosion, wind erosion does not take place where there is good soil cover. On lands under permanent vegetation such as grass land and forests it is no problem. Co-ordinated control measures are much more difficult in the case of wind erosion than with water erosion, since the velocity of the vehicle in the case of water is determined only by local topography, whereas the velocity of the wind is a matter of climate plus local factors. The principles are however the same and a complete programme covers two phases, namely, the control of the areas from which the soil is removed and the control of the deposits.

Control of sand drifting from the coast.—Sand is thrown up by the sea at high tides in some places. The wind catches the soil particles as the tide recedes and blows them inland either by rolling up the beach or by lifting and airborne transport. As the particles roll up the beach they increase its height to form a sand dune and it is from the ridge of the dune especially that air borne distribution takes place. Inland the particles form unstable dunes which move with every severe wind and gradually encroach on other areas. The classic case of control of sand drift of this type is the Landes of France.

Control consists of first erecting a mechanical obstruction formed by one or more lines of paling about 1 inch thick, 6 feet 8 inches wide and 6 feet long, small spaces being left between each plank. As sand collects, these lines are raised until the dune so formed has been increased to its proper height of about 30 feet above sea level. This dune is known as the littoral dune. It is fixed by stocking it with suitable grasses such as the *murram* (*Psamma arenaria*), a grass with long soil binding rhyzomes. Where accretion is taking place new littoral dunes are started by the same method, and the dunes previously formed gradually pass inland. These measures effectively stop the drift of the sand inland. Steps are taken to fix the sand dunes already in existence so as to prevent further movement along the seaboard. Natural cover is allowed to come in, consisting of woody shrubs. If it does not grow naturally it is planted or sown. This constitutes a zone of protection for the areas to be planted with trees, and is often badly grown. Without it, however, the strong sea breeze would kill the young plants of the species which are planted behind it. Strict protection against grazing is enforced so as to conserve all possible vegetative cover. The final stage is reached when the original tree crop usually consisting of conifers has sufficiently improved the soil for a broad leaved crop to be grown.

In Madras, though no complete project has been carried out, considerable planting of sandy littoral areas has been done by the Forest Department with *Casuarina equestrifolia.* This has given protection to agricultural lands and has provided large supplies of fuel.

Control of internal sand drift.—Here the problem is more complicated. The areas from which the soil drifts is usually cultivated, the only exception being areas where deposits from previous drift are themselves moving. In these areas various improved agricultural practices will limit the amount of drift. These can be assisted considerably by supplementary measures such as the growing of effective fences of *Euphorbia*, aloe, etc., and growing trees such as *Acacia leucophlœa* (white babul), *Albizzia lebbek* (*vagai*), *Azadirachta indica* (*neem*), etc. The object of these fences is to reduce the ground velocity of the wind. The species used for fences should not adversely affect the agricultural crops. The effect of the fences will also be increased if trees are planted around farm houses and buildings especially to the windward side, while groups of fruit trees scattered here and there are always an advantage. It will be seen therefore that the first phase of control will have to be done by the cultivators themselves, but it is the foundation of subsequent control measures.

The second phase consists of dealing with the deposits of sand. Here the general principles laid down for dealing with sand drifting from the coast can well be applied, the object being to halt and fix the drifting soil particles on the windward side of the zone of deposit. The first and essential step is to decide once and for all the boundaries of the area to be dealt with. Complete closure to grazing is necessary to allow the maximum natural production of ground cover.

An example of this type of work is that of the Kudurimozhi *teri* * of Tinnevelly district. Here the drift of soil is caused by the south-west monsoon. As an area of deposit and also of drift within itself it has been known for about a century. Before reservation in 1892, cultivation with palmyra, *Acacia planifrons*, *Dalbergia multiflora* and the shrub *Dodonea viscosa* was tried as a means of inducing vegetative cover, but this failed except for a certain amount of success with palmyra. Again sheep and goats were penned on the area and fed with seed of various tree species such as *Acacia planifrons.* This gave little success. The area was constituted as a reserved forest in 1892 and totalled some 13,000 acres. The Forest department has worked steadily and systematically. At first the western margins were regenerated with palmyra, *Acacia planifrons*, *Albizzia lebbek* and *Azadirachta indica* together with the shrub *Dodonea viscosa*. The northern margin which was more promising was regenerated with

* Meaning "Sandy tract."

the same species and also with *Dalbergia multiflora* and cashewnut. Extensive areas elsewhere have been regenerated with palmyra. It has been found that while palmyra alone assists, it is inadequate to achieve complete fixation. This needs no explanation for this species provides little ground cover. Afforestation with the various other species mentioned above was however entirely successful. So promising was the reclamation work that in 1924 a reclaimed area of nearly 2,000 acres situated in the vital protection belt to the west was disreserved in response to a local outcry for land for grazing and cultivation. At the present time this area once reclaimed is fast reverting to its original condition, exposing the interior again to heavy wind drift. This shows the necessity for determining the boundaries of such protection projects and adhering to them always.

A further example of highly successful work on a smaller scale is also to be found in Bellary district in the Moka plantation of some 1,000 acres along the banks of the Hagari river, where *Dalbergia sissco* (*shisham*), *Pongamia glabra* (*pungam*), *Azadirachta indica* (*neem*) and *Albizzia lebbek* (*vagai*) have been introduced systematically since 1907 and have resulted in the complete control of wind drift.

Wind brakes or shelter belts.—The use of trees to reduce the effect of high winds in agricultural areas has been known for many years. Winds considerably increase the aridity of an area, for they hinder the formation of dew, dry up the topsoil where exposed and cause excessive transpiration among plants, resulting in the drying up of the leaves. By their force they bruise the leaves and cause heavy falls of immature fruits in orchards. Belts of trees known as wind brakes or shelter belts have long been grown for protective purposes by experienced farmers in areas such as the Prairies of America or the Steppes of Russia, where natural grassy plains devoid of tree growth were being opened up. Such belts should run at right angles to the prevailing wind. In width they should be not less than 50 feet and rarely wider than 100 feet. Planting should be done at a relatively wide espacement and in quincunx or double square formation to allow low branching and at the same time offer the maximum frontal resistance to the wind. A suitable espacement is 7–10 feet on the plains. Towards the windward side of the belt species should be thick foliaged and hardy and it may even be necessary in some areas to establish a line of shrubs first before the tree species can be introduced.

The protective effect of shelter belts is governed by the height and varies up to a limit of 10 times the height. Thus a belt 40 feet high would protect a leeward area of about 400 feet in width after

which a further belt would be necessary. In selecting species, therefore, this fact has to be taken into consideration. For the plains for example the following would be a suitable selection starting from the windward side:—

(1) *Shrubs* such as *Agave americana* (aloe), *Euphorbia* (*tirucalli*), *Jatropha curcas* (*kattu amunak*), *Thevetia neriifolia* (*ponnarali*), *Dodonea viscosa* (*virali*).

(2) *Trees*—

(*a*) First line—*Pongamia glabra* (*pungam*), *Anacardium occidentale* (cashewnut), *Thespesia populnea* (*puvarasu*).

(*b*) Second line—*Azadirachta indica* (neem), *Acacia planifrons* (*odai*), *Prosopis juliflora* (exotic), *Cassia siamea* (*ponavaram*), Bamboo, *Acacia leucophlœa* (*vellavelan*).

(*c*) Other lines—*Albizzia lebbek* (*vagai*), *Casuarina equestrifolia* (*chavuku*), *Tamarindus indicus* (tamarind).

Such species under average conditions would result in a belt rising up to 60 feet in height on the leeward side under reasonable conditions of agricultural soil.

In Madras little of such work has been done except that recently a shelter belt has been established along the bank of the Hagari river in Bellary district to prevent sand drifting into the adjacent cultivated lands. The results have been costly but fairly successful though in the opinion of many the width of the belt of 33 feet is too narrow giving only five rows of trees. It is often necessary to water the seedlings artificially to establish them.

In the planting districts of the Nilgiris wind belts have been established on a large scale using exotics introduced into the area many years ago such as *Cupressus torulosa*, *Acacia melanoxylon*, *Acacia dealbata*, *Acacia decurrens*, *Hakea Sp.*, and *Callitris dhomboidea*. Such species are quite unsuited to the conditions of the plains however, and their object is to modify climatic conditions and not to control sand drift. The importance of shelter belts is shown however by the inclusion of a shelter belt programme covering a total of 865,000 acres in the second five-year plan in the U.S.S.R. and 1,282,000 acres in the programme for control of wind drift in the Great Plains region of the United States of America.

Once established, shelter belts have to be maintained especially while they are growing up by thinning them out so as to give space for branch development. It is unwise to attempt to grow first-class timber. To check the wind, trees with large strong crowns are required. On the windward side leaf cover should be so manipulated that it practically reaches ground level, if necessary by pegging down the branches and by topping the leading shoots to prevent further

upward growth. Properly tended they have a long life, and at the same time give appreciable yield of rough timber and fuel.

Prevention of sand drifts along canal banks and near irrigation works.—The Buckingham Canal is a navigable tidal canal running close to the east sea coast in Madras Province. It is 258 miles long of which a length of 64 miles lies south and 194 miles north of Madras City. Since the canal is a coastal one, it traverses mostly sandy regions along its course. To prevent the canal being filled up with sand drift tree belts have been provided along the whole reach wherever possible. These mostly consist of casuarina, margosa, cashewnut, *babool*, tamarind and palmyra. These trees especially the first four, grow very quickly in loose and sandy soils and efficiently protect sand drifts, and also stand well against cyclones which are very common on the Coromandel coast. In miles 36 to 43 and 58/3 to 64/0 of South Buckingham Canal, the canal goes in deep cutting in many places, with high sandy spoil banks on either side. These spoil banks have been planted with casuarina, cashewnut, *babool* and other junglewood trees which in addition to their use as wind belts serve as useful fuel trees. The Palar river flood bank is formed of pure sandy soil for a length of 1½ miles from Palar North lock. It has been stabilised by a thick plantation of casuarina. Erosion of the bank by wind has thus been arrested. In the North Buckingham Canal between miles 27 to 58 where there is a high west bank of sand, plantations have been done all along to prevent erosions and breaches by floods in the Pulicat lake. The plantation consists mostly of *babool*, margosa and other jungle wood. *In soudu* * soils of the Buckingham Canal reach between miles 178/3 and 178/7, plantations of screwpine and *kali-manda* were not successful. In this reach all attempts to raise plantations to prevent *soudu* drift has been unsuccessful till now and maintenance of required depth of water for navigation in that reach of the canal is an extremely difficult task during summer months from April to July.

Sandy banks of Allur tank supply channel, Iskapalli branch channel, Varini taluk sluice channel and Zuvaldinme branch channel in Nellore district on the sea coast have all been protected from erosion by planting with goat-foot creepers, *erukkai* or *jilledu*, *nanal*, *darba* grass and *kolinji* plants. *Kolinji* plants (*Tephrosia purpurea*) have a very good demand as green manure for wet cultivation.

In pure sandy soils, casuarina, screwpine, *kali-manda*, babool and cashewnut trees are found very efficient in arresting sand drift.

* *Soudu* soil is a saline soil with visible surface salt efflorescence, largely impervious to water and getting slushy when wet, if trampled. The salt incrustations are generally sodium carbonate and chloride and occasionally sodium sulphate. The soil is a very poor supporter of crops.

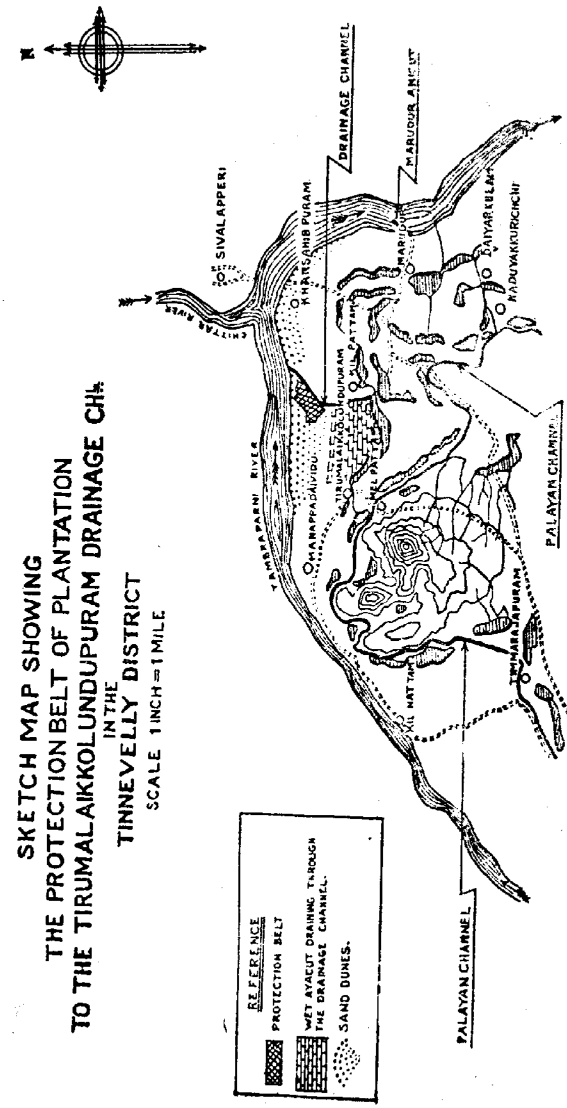

SKETCH MAP SHOWING
THE PROTECTION BELT OF PLANTATION
TO THE TIRUMALAIKKOLUNDUPURAM DRAINAGE CH.
IN THE
TINNEVELLY DISTRICT
SCALE 1 INCH = 1 MILE
REFERENCE
PROTECTION BELT
WET AYACUT DRAINING THROUGH THE DRAINAGE CHANNEL.
SAND DUNES.
SIVALAPPERI
CHITTAR RIVER
TAMBRAPARNI RIVER
DRAINAGE CHANNEL
MARUDUR ANICUT
PALAYAN CHANNEL
PALAYAN CHANNEL

Fig. 157

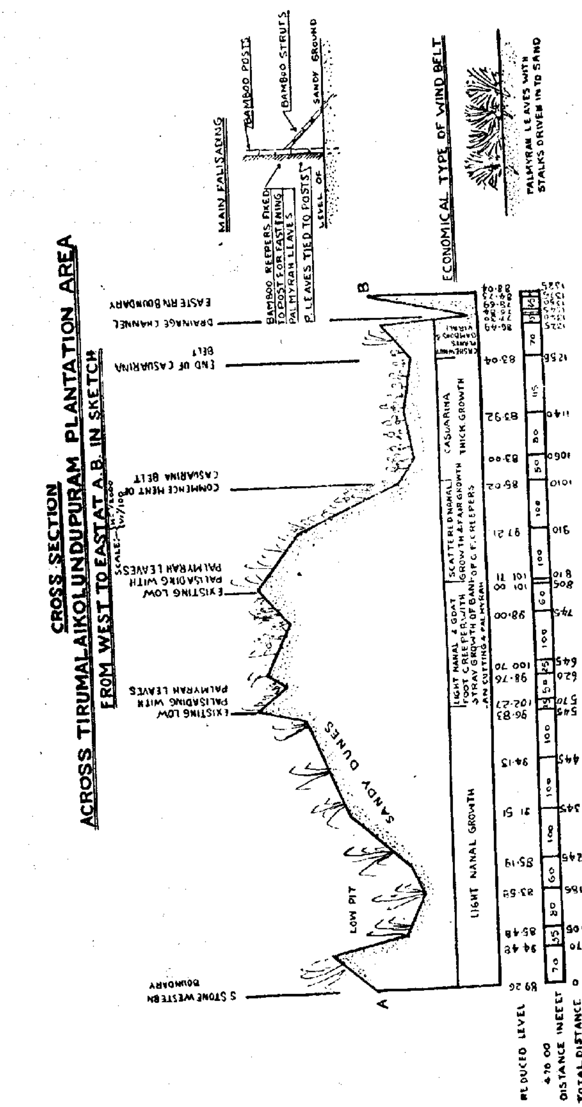

CROSS SECTION
ACROSS TIRUMALAIKOLUNDUPURAM PLANTATION AREA
FROM WEST TO EAST AT A.B. IN SKETCH
MAIN PALISADING
BAMBOO POSTS
BAMBOO STRUTS
SANDY GROUND
ECONOMICAL TYPE OF WIND BELT
PALMYRAH LEAVES WITH STALKS DRIVEN IN TO SAND
CASUARINA THICK GROWTH
LIGHT NANAL GROWTH
SANDY DUNES
LOW PIT
REDUCED LEVEL
DISTANCE IN FEET
TOTAL DISTANCE

Fig. 158

Casuarina plants are planted during the latter part of the monsoon period. If planting is done as soon as the monsoon starts, the plants will not survive on account of excessive rain. Usually seedlings two to three years old are planted at two to three plants in each hole 3 to 4 feet apart. They require watering during two consecutive summers after planting, after which they do not require any attention. Cashewnut trees are grown by putting good cashewnut seeds during rainy season in holes 9 inches to 1 foot deep made by any stick 1 inch in diameter. No watering is done. *Kali-manda* is grown from cuttings planted during rainy season. This forms a good hedge. Palmyras are grown from seeds which are pre-sprouted by heaping ripe palmyra fruits and covering the heap with some rubbish which is kept wet. Palmyrahs grow very slowly and in their early stages if planted closely in rows prevent sand drift. They do not require any watering and attention. Castor plants grow very well in sandy soil and protect the area from sand drift.

The following case of prevention of obliteration of certain irrigated areas from sand drift in the Tinnevelly district on the banks of the Tambraparni river * is reported by the Madras Public Works Department. The Tambraparni river (which is the main source of irrigation in the Tinnevelly district) turns almost at right angles at a point about 7 miles north-east of Palamcotah. At this bend large mounds of loose sand have formed and as the yearly floods last only a short period, these mounds are exposed to the full blast of the south-west monsoon winds which blow with great severity through the Shencottah gap of the Western Ghats. These annual sand drifts have rendered extensive areas unfit for cultivation by depositing drift sand over them. Ultimately the sand drifts became a menace to a drainage channel which was the only drainage outlet for about 300 acres of wet lands near Tirumalaikolundapuram. Every year the ryots used to clear the channel of its sand and arrange for the proper drainage of their wet lands. This evil was continuing till 1927 when it was found that the position was really serious. The Public Works Department considered several schemes of which the following are noteworthy:—

(1) Laying a 3-foot diameter pipe conduit to carry the drainage;

(2) the construction of a masonry tunnel;

(3) the re-alignment of the drainage channel in the wet lands.

These were all found to be costly. After a careful study of the

* Madras Public Works Department Circular Memo. No. 2124/39 A-11, dated 11th January 1941.

situation, the following operations were carried out in consultation with the Forest department:—

(1) Formation of ridges in the sand itself to retard drifting sand and to permit planting;

(2) Planting grasses, shrubs and trees;

(3) Forming "Wind belts" to protect the young growth; and

(4) Watering and watching the plantations.

The whole area was declared as "Reserved" under the Madras Forest Act. To give immediate relief to the channel, planting with trees, shrubs and seeds was done over a 300 feet wide belt to the windway of the channel and along the entire affected area. Casuarina and bamboo seedlings and banyan (*Ficus bengalensis*) cuttings were put in and this was followed by experimental sowing of *odai* and *virali* seeds during the north-east monsoon of 1935. In the succeeding summer in spite of careful watching and watering, casuarina alone was found to survive. *Odai* and *virali* were smothered by sand drifts. To overcome this, "wind belts" by means of screens of palmyra leaves strutted with bamboos were erected to a height of 5 feet and for a length of 800 feet. As sand drifts piled up against these screens they were raised gradually. Two rows of such screens 30 feet apart were erected. During the monsoon months of 1936 (October-November) *nanal* grass was planted. Also cashewnut trees, *maruthu*, *usil*, margosa, coconut, palmyra and bamboo cuttings were planted on the sandy soil to stabilize it.

From 1937 a new type of "wind belt" was tried. It consisted of planting palmyra leaves with stalks driven down into soil. These afforded good protection for the plantations against drifting sand. By careful watching and maintenance the sandy soil has been stabilized by a cover of forest and the drainage channel is now immune from threat of annihilation by sand drift. The whole scheme has cost the Government Rs. 7,340.

A case of control of sand drifts near Proddattur where sand was blown from the Pennar during the south-west monsoon and obliterated an irrigation channel was similarly dealt with, in this case with palmyra *thattis* * tied to posts driven into the ground and had very good effect. The work is still in progress and its ultimate effect will be watched with interest.

Another case where sand drifts from the sea beach filling up and choking an outfall drain making it ineffective was very successfully tackled by extensive cultivation of casuarina in the hinterland. The outfall drain about 100 feet wide had no trouble from sand drift after casuarina cultivation was resorted to.

* Meaning "Trellis fencing."

CHAPTER XVII

CONTROL OF FLOODS

SOIL CONSERVATION has a distinctive bearing on flood control in rivers. Anti-erosion methods adopted primarily for soil conservation purposes often help to prevent heavy floods. By slowing down runoff of rain water in order to curb soil erosion, the volume and velocity of water which might otherwise contribute to floods are also controlled. Similarly, soil which is held on the ground by erosion control methods is prevented from entering streams where it would cause silting and raising of stream beds resulting in reduction of flood-carrying capacities of the streams. Thus, if the watersheds of major rivers are protected from soil erosion the danger from floods should not be serious.

In the Madras Province, there are no statistics to show that heavy floods in major rivers are directly attributable to soil denudation. Heavy floods in major rivers like the Godavari, the Kistna and the Cauvery, are the result of continuous rainfall during the south-west monsoon over very extensive areas of their catchments. But the deltaic portions of the Presidency on the east coast are susceptible to heavy flooding on account of abnormal rainfall during the north-east monsoon when the rivers practically do not get any runoff from their hilly and upland catchments.

In all river basins in South India there are groups of tanks which are interelated to one another. These tanks either receive the surplus from upper tanks or drain their surplus into lower tanks or do both. Ultimately, the whole surplus water of the lowest tank is discharged into the main river. It will be evident that considerable economy of water is obtainable from the system of grouping of tanks because the surplus water of each tank and also the drainage from its *ayacut* lands are caught up by the next lower tank. One great disadvantage of this system of grouping of tanks however is that a breach in an upper tank exposes all the tanks below in the series to a risk of similar failure. During normal monsoon rains these tanks have sufficient surplussing capacities and are safe against breaches. But during heavy cyclones it is not uncommon to see heavy damages caused by

breaches in these groups. More damages have been caused by such breaches than by actual floods from main rivers.

The question of control of floods on rivers in South India is confined to deltaic portions where rich agricultural lands are to be protected from submersion.

The following are the possible devices for flood control in rivers:—

(1) Storage or retarding reservoirs.

(2) Flood embankments or levees and improvement of channels.

The former retard the flow of flood waters and the latter hasten the flow of flood water from the watershed.

Storage or retarding reservoirs.—Reservoirs as merely flood moderators to protect agricultural land are uneconomical as the cost of their construction will be quite disproportionate to the value of land protected. In the Madras Province no instances are existing of reservoirs used solely as flood moderators. In the United States of America, their use in the past has been restricted to cases where the property protected has a very high unit value such as big cities and industrial areas. The flood control system of the Miami district in the United States of America, which has proved very successful, would never have been economically feasible had it not been for the high valuation of property, the great density of population and the importance of industries located in the flood area.

A reservoir solely intended for flood moderation cannot fulfil its function unless it can be emptied as soon as practicable after floods. Rapid emptying is necessary in flood storage reservoirs since such reservoirs have their highest value when empty. Such reservoirs have a limited value for other useful purposes such as water-supply, power development and irrigation.

In a territory where rainfall is more or less deficient there is often an agitation for a combination of irrigation and flood protection by reservoirs. Storage of flood water to be released during period of scarcity would seem to offer considerable promise of combined use. If there was any regularity in the quantity or the period of occurrence of floods, this principle would work very well. But floods vary so much in volume and time of occurrence that in most cases it is either impossible to obtain assurance of flood protection by having the reservoir empty at the time of flood occurrence or to carry the flood water over a protected period of drought for irrigation. For irrigation, water-supply must be dependable. If high floods come into the reservoir when the irrigation storage is high, the flood moderating influence of the reservoir will be very little. However, after a careful study of various factors it may be possible to formulate certain

rules of regulation in irrigation reservoirs and considerable flood moderating effect obtained.

Dual purpose reservoirs to serve irrigation and flood control, or power and flood control, by providing separate storages for each within the same reservoir have great potentialities in India. The Mettur reservoir in the Madras Province has a gross capacity of 95,660 million cubic feet. It has been constructed mainly as an irrigation reservoir. But on account of its vast capacity it acts as a flood moderator also. The valuable deltaic lands in Tanjore and Trichinopoly districts are protected from floods from the Cauvery river derived from the runoff of its extensive hilly catchment area of 16,300 square miles above the reservoir. The total catchment of the entire Cauvery river is 31,000 square miles. It is estimated that if the Mettur Dam had been built prior to the superflood of 1924, the disastrous effect of that flood would have been flattened out by about 15 per cent by the timely manipulation of the reservoir surplus water.

The Norris dam on the Clinch river, a tributory of the Tennessee river in the United States of America is an example of combined use of the reservoir. The upper part of the reservoir comprising 1,400,000 acre feet is reserved for flood control storage whereas the lower part is to regulate the flood for navigation and power.

" A historical example of how a reservoir can effect floods is that of the Gohna lake caused by an earth slide across the Birahi Ganga Valley in British Ghanwal. This slip created a reservoir of estimated capacity of 8,000 million cubic feet and when the barrier burst, it created record floods in the Ganges in the United Provinces in August 1894." [5 (*d*).]

Pickles in his book on *Drainage and Flood Control* discusses the merits of reservoirs in the role of flood control, as follows: " Reservoirs as a means of flood prevention are applicable mainly to small water-sheds and are specially effective in preventing floods from intensive precipitation of the cloud burst type, also if the lands to be protected are near enough to the reservoirs." For medium-sized watersheds of about 5,000 square miles a single reservoir is seldom sufficient to prevent floods at the lower end of the watersheds but a system of reservoirs on each of the principal flood producing tributaries will in many cases solve the flood problem. The Miami flood protection works are an example of this type. " For large streams, flood protection cannot be economically secured by storage reservoirs or retarding basins. The six reservoirs constructed at the head waters of the Missisipi river storing 97,000 million cubic feet reduce the flood flows in the upper part of the valley, but 100 miles below St. Paul which is 413 miles from the uppermost reservoir and 168 miles from the lowest the effect of the reservoir is negligible."

It may be generally stated that reservoirs in the upper reaches of major rivers in the Madras Province will have very little influence on high floods in deltaic regions due to heavy rains during north-east monsoon.

Reservoirs for flood control are unsuited if the flood waters that are impounded contain heavy silt and solids. Reservoirs across such rivers will get filled up with silt in a short time and their capacities for storage and flood absorption will become negligible. In India, the possibility of flood control by reservoirs is being considered by the Central Board of Irrigation. There are many excellent sites for constructing storage reservoirs in different parts of the country.

Flood embankments or levees.—The principal method of flood control in the lower reaches of all the major rivers in the Madras Presidency is by confining the flow of flood water in the river by erecting flood banks on either side of the river course. These flood banks are located fairly away from the river margins, so that they might not be undermined by swift currents. Usually the land lying between the flood bank and the river margin contains scrub jungle, trees and other vegetation that retard the flow of water and consequently the velocity of water flow near the bank is not such as to endanger the safety of the bank. In the case of the Akanda Cauvery and the Coleroon rivers, the flood banks are 1½ to 2 miles apart whereas the actual width of the river is less than one mile. In the case of the Godavari river, the flood banks are one mile apart at Polavaram, 1½ miles apart at 5 miles below Polavaram, 3 miles apart at 10 miles below, 1½ miles at the Railway bridge at Rajahmundry and 4 miles apart at Dowlaishwaram Anicut. Usually these flood embankments are not less than 10 feet wide at top with side slopes of 2 to 1. The crest level of the banks are kept 3 feet above the maximum observed flood level in the river. No special precautions are taken in the construction of these banks. Available earth from the river margin or adjoining land is used for the formation of the banks. If sand is met with, the slopes are flattened to 3:1. The slopes are usually protected from erosion and gullying by means of plantations and turfing. These flood banks are maintained properly and watched during flood seasons. If a river in its natural meandering course attacks any portion of the flood bank, then the bank is protected with stone revetment and subsiding aprons. If there is land available it is better in such circumstances to realign the flood bank along a new course further away from the original alignment. Minor drainage inlets should all be sluiced and controlled to prevent flood waters backing up along these banks and causing submersion of low-lying lands.

These flood embankments are called "levees" in America. *Sir Hanbury Brown*, in his book on *Irrigation and its Principles and Practice* states that confining the flood flow of rivers within embankments or levees will tend to gradually raise the bed of the river with the result that after some years the height of the existing embankments will have to be raised to prevent overtopping.

Bellassis (1931) says that "Embankments on both banks of rivers in Bengal have raised the flood levels and probably the bed levels. On the Missisipi it has raised the flood levels, but not bed levels. Embankments on the Indus and the Chenab are not known to have caused a rise in the flood levels but the embankments are far apart—on the Indus they are 6 miles apart." Major General Jadwin, Chief of Engineers on the Missisipi Flood Control, says: "A widespread fallacy about levees is the assertion that they raise the bed of the river resulting in the long run in the formation of an elevated trough. Surveys and measurements carried on for over half a century on the Missisipi show that the bed of the river has not been raised by levees." [*Central Board of Irrigation, Publication No.* 16, pages 113–114.]

It may be stated that in large river systems a combination of reservoir control with flood embankments in the lower reaches and dredging and deepening the river bed will contribute towards a better flood control than by any single method. In small streams and tributaries of large rivers, construction of flood absorption reservoirs alone may have the desired local effect.

Effects of forests on flood control.—In Chapter III the effect of natural vegetative cover on soil erosion was discussed. Both soil erosion and floods result from the same cause, namely the rate of runoff. High runoff entails heavy erosion and heavy floods. In fact, erosion control and flood control are inseparable, for the control of the one automatically results in the control of the other.

In many countries, and especially where agriculture has extended rapidly during the past century, floods continue to increase in volume and the cost of attending to flood damages is increasing. Especially is this the case in areas with extreme climates. The increase in the intensity of the floods is in no small measure correlated to the decrease in the area of land covered with natural vegetation whether grass or forest.

By way of recapitulation, let us again study briefly the effect of forests on runoff. The rain is interrupted by the crowns of the trees and shrubs and reaches the layer of humus covering the top soil in the form of a spray with no pulverising power. The humus acts as a filter, removes impurities and passes the clear water on to a

granular topsoil full of roots and rich in organic matter and a very active microfauna and therefore in prime condition to absorb the maximum possible amount of water. The roots in the top soil assist the water in penetrating deeper down into the soil. Experimental stations in the United States of America have studied the rates of infiltration of water intensively and have shown that—

(1) the turbidity of the surface water has a great effect on infiltration, as the small soil particles in suspension block the pores on the surface of the topsoil. Experiments showed the rate of infiltration of water containing 1·9 per cent of silt to be only one-tenth that of clear water;

(2) the presence of organic matter in the soil increases the rate of infiltration;

(3) a high developed microfauna in the topsoil increases the rate of infiltration; and

(4) the channels opened up by the root systems of plants also increase infiltration.

Thus, all the conditions conducive to rapid infiltration are present in land under forest cover. The importance of the humus layer cannot be emphasized too often. It acts as the filter, gets decomposed to provide organic matter for the topsoil and a highly developed microfauna is engaged in the process of decomposition.

The capacity of the soil to absorb water is often overlooked. Many types of soils can absorb as much as 33⅓ per cent of water by volume. In theory therefore one foot of soil would require four inches of water to saturate it. If the rate of absorption and the rate of precipitation were the same, this ideal would be realized, but many factors interfere with the rate of absorption. The potentialities of soil however remain and warrant careful consideration. The greater the amount of moisture absorbed, the less will be the runoff, and the less the intensity of floods.

In modern times, vast areas of forest have been either totally destroyed or denuded by the hand of man, by overcutting, overgrazing, fires, etc. A philosophy of the inexhaustibility of such natural resources has held sway down the ages, for such resources were considered unlimited and it was therefore easy to be prodigal of them. The penalty is now being paid in soil loss, silting of river systems, storage systems, distribution systems, and in the reduction of the water ways of cluverts and bridges, etc. Though this has been foreseen and emphatically forecast for many years little has been done. From the middle ages, foresters have pressed for the retention of areas of forest adequate to supply the demands of the people and to protect water-supplies, at the same time preventing land slips,

floods, etc. Their protestations against over-exploitation, over-grazing and forest fires have largely fallen on deaf ears. Within the last decade however, a change of outlook can be noted, chiefly owing to the attention paid to the complementary subject, soil erosion. Nowadays, there is an increasing volume of opinion in favour of developing a policy of water conservation from its source, and this will automatically control floods to a large extent. The view is that nature herself laid down a design of flood control which has been changed by man to his own disadvantage. It is therefore necessary for man to revert to this design as far as possible, and to improve it where he can. Emphasis is laid on the necessity for maintaining adequate forests in good condition in the hill catchments to reduce primary runoff and increase the period of flow in springs and streams. Taking average figures of proportionate areas from countries where scientific forestry has long been practised a minimum of 20—25 per cent of the total area is found to be necessary to achieve this purpose. Many countries have allowed the area under forest to dwindle to a much less figure. Lastly, the monetary benefits that would accrue from an appreciable reduction in maximum flood levels combined with a longer and steadier flow in water-sources are tremendous, and this is especially the case in areas with arid climates where water is a *sine qua non*.

CHAPTER XVIII

EROSION AND MALARIA

THERE IS one other factor of great national importance which is largely influenced by erosion and anti-erosion works; that is their effect on the propagation of diseases. It will be seen from the foregoing chapters that the problem of erosion and its control is in fact a problem of regulation of waterflow. Water collection has an important bearing on health inasmuch as it leads to breeding of mosquitoes. Among the diseases conveyed by mosquitoes the most important is malaria. Malaria causes millions of deaths every year either directly or indirectly. Many millions of people suffer to a greater or lesser degree from physical disability in consequence of attacks of this disease.

Malaria is caused by human malarial parasites. These occur only in man and certain *anopheles* mosquitoes serve as the only known means by which the parasites are conveyed naturally from man to man.

Other animals besides man harbour various kinds of malaria parasites, but none of these are known to cause the disease in man. Similarly, the human malaria parasite is incapable of causing any disease in animals.

There are three main varieties of mosquitoes: (1) *Anopheles*: (2) *Culex* and (3) *Aedes* (*Stegomyia*). Of these the first variety alone is capable of transmitting malaria. Neither *Culex* nor *Aedes* (*Stegomyia*) can convey malaria.

The group *Anopheles* includes innumerable species. Only very few of them are in their turn capable of acting as transmitters of malaria. The important species which act as carriers in South India are: (1) *Anopheles culicifacies*, which prevails in most of the deltaic areas and the plains, (2) *Anopheles stephensi* which is prevalent in some selected areas; (3) *Anopheles sundaicus* which is prevalent in the salt marshy coast in Vizagapatam district; and (4) *Anopheles fluviatilis* which is present in foot hills and mountain slopes.

A few other species which occur in South India do occasionally carry malaria infection, but they are either small in number or the

amount of infection transmitted by them is not large enough to be considered important.

It must be remembered that in this as in many other types of disease-carrying insects, it is only the female of the species that bites men and animals. The male does not bite and does not need any blood meal. Only the female is capable of transmitting disease from man to man.

Malaria parasites have two phases of existence: (1) Asexual phase in which the parasite grows and multiplies in the blood of man. (2) Sexual phase in which the earliest stage is found in human blood. This early stage does not cause fever. Its only role is in the propagation of the disease through the mosquito to another man.

When a mosquito of a suitable kind sucks blood containing these sexual forms, the parasite undergoes further development inside the mosquito and eventually multiplies into numerous slender bodies which are injected into any person who is bitten by that mosquito.

Factors influencing spread of malaria.—There are several factors of importance in connexion with the spread of the disease such as climate, the presence of suitable breeding grounds, the presence or absence of protection against the bites, the presence or absence of animals other than human beings, etc.

The duration of the malaria season varies greatly. In northern countries, the conditions which favour transmission exist only for a short time and nearly all the fresh infections occur during a period of one or two months. In places near the equator where the seasonal variations in rainfall and temperature are slight, malaria may show little change in prevalence from month to month. In these places, the occurrence of fresh cases may be prolonged to two, three, four or five months or in some cases even throughout the year. As a broad general rule, the chief season of prevalence falls in the later months of the rainy season.

Temperature, as far as India is concerned, can only be looked upon as a predisposing cause affecting the breeding of *anopheles* and the development of malaria parasites in *anopheles*. One of the causes of reduced malaria in very hot dry areas is the great reduction of *anopheles* brought about by the extreme temperature. While a high temperature may favour development of the parasite in the mosquito, concomitant atmospheric dryness may kill mosquitoes.

The great importance of moisture in the soil is shown by the association of malaria with marshes, swamps, banks and drying pits, rivers and sea-coast. The typical malarious locality is low and marshy or is in the vicinity of rivers, lakes and canals. Some regions in India which are almost free from malaria in the hottest part of

the dry season become very malarious shortly after the commencement of the rains and their malaria intensity becomes greater during the autumn. Moisture is essential for the development of the eggs and larvæ of the *anopheles* mosquitoes.

The amount of rainfall and the period over which rainy season continues have an important influence on the prevalence and distribution of malaria in India. Rainfall conduces to the production of malaria, because it favours the development of *anopheles*. Heavy torrential rains have the effect of washing away the mosquito larvæ, while long intervals of dry weather may dry the pools leading to the destruction of larvæ. The most favourable conditions for mosquito breeding are intermittent and moderate rainfall with intervals of sunshine.

In general terms it may be stated that malarial fever is most prevalent in India during the years of heaviest monsoon. This is particularly the case in the level plains and localities in which drainage is slow or in any way obstructed. Conversely, in comparatively dry areas where there is poor rainfall the incidence of malaria is below the average.

The extent to which the water table rises above the surface of the soil and causes pools of water which become mosquito breeding places, constitutes a dominant feature influencing the prevalence of malaria.

Soil erosion and its relation to malaria.—In the problem of erosion in its relation to malaria, this factor is particularly noteworthy. The actual geological condition is not significant but the porosity of the soil is most important. A soil which permits rapid surface as well as subsoil drainage is unfavourable to malaria. A soil that holds up water in small collections such as ponds, pools, etc., fosters malaria. A high water-level in the soil is usually associated with malaria.

Vegetation, *per se*, has nothing to do with malaria. Malaria may be intensively prevalent where little or no vegetation exists, and it may be absent in the densest jungles with luxuriant vegetation. The disease is entirely absent in high altitudes. In India, malaria has been known to occur up to 6,000 feet. Temperature unfavourable to the development of the parasite in the mosquito appears to be the most important factor in connexion with the absence of malaria at high altitudes.

Soil erosion, whether of the sheet or gully type or in the beds of streams, results in the rapid washing off of the comparatively porous, soft, surface-soil. The substratum left behind is too hard for rapid erosion. Its level is however not smooth allowing good runoff but is studded with depressions and hollows which permit formation of pools. In the case of rivers and streams, the formation of pools and

rapids depends on the nature of the land. A too rapid scour in the bed caused by high intensity flow accounts for this. A too rapid run-off caused by denudation also leaves the bed dry for most of the area except for such water as is left in the pools. A continuous flow over the bed forming one complete sheet of water bank to bank, is not quite favourable for the breeding of mosquitoes.

When the soil is washed down the hill side, it often accumulates at the foot hills as a soft muddy puddle which holds water. The impressions left by the treading of cattle and other animals are quickly filled with water and form breeding grounds for mosquitoes.

When sheet or surface erosion takes place we have a few pools here and there which help breeding. The gullies do not have uniform soils or beds and usually lead to the formation of pools in which the mosquito larvæ can thrive.

Vast areas throughout the world which were at one time endemically malarious have been freed from malaria to a great extent, while in some cases it has completely disappeared. These satisfactory changes often mainly affect drainage and cultivation of the soil by which the breeding places of mosquitoes have been reduced. Of the simpler anti-mosquito measures, the most comprehensive and the most generally useful is that of doing away with all stagnant collections of water in the neighbourhood of dwellings, villages, towns, etc., by filling up the hollows and irregularities or by draining them.

Anti-mosquito drainages.—Anti-mosquito drainage usually includes the institution and maintenance of one or more of the following works: ditching, plain or lined; subsoil tile drainage, vertical drainage and absorbing wells; rechannelling of water courses and training and canalising wandering streams, water courses and sluggish waters generally, and control of irregular channels; taking streams underground; salt water drainage, including dyking, construction of tide gates, prevention of silting and pumping. In association or not with drainage we may have to carry out general surface levelling. This comprises the filling in of ponds, marshes, and all manner of irregularities of the surface; the removal of their waters by drains or cuttings, small, medium or large, the reclaiming and re-vitalising of swamp, attention to culverts and ditches; restriction of wet cultivation; regulation of the flow in irrigation waters; and regulation of drains alongside roads and rail-roads. In short, drainage includes all classes of work required to carry off and abolish open collections of water and to lower the sub-soil water level; it also embraces eradication of aquatic vegetation and clearing of all natural and artificial water channels.

Large scale drainage is called for wherever the level of the subsoil water is high or the land is water logged and where there are marshes or other large collections of water. Such large drainage schemes always take time to show any distinct influence for the better. Usually, it is not until the second year that there is an appreciable diminution in the incidence of malaria. The decrease becomes more marked by the end of the third or next year. It should also be remembered that large scale comprehensive drainage works take several years in their very execution, and it will not be until the works reach completion that any beneficial effects will begin to be felt. Such drainage schemes require the technical knowledge of a Public Health Engineer with some experience. The area to be drained should be inspected when it is at its worst. It should also be remembered that any system of drainage requires well organized, efficient and constant supervision.

A few of the important points in connexion with the application of drainage on a large or a small scale in anti-malarial sanitation are dealt with below. They may be roughly grouped into two major heads: (1) regulation of surface waters, and (2) drainage of marshes and of sub-soil water.

Regulation of surface waters.—The chief surface waters which need regulation in India are rivers, streams, canals, lakes, ponds, etc.

Among the methods in operation in the regulation of rivers and streams, the important are: vegetation of mountain slopes, stepping and traversing of slopes, damming and sluicing, rectification and rough canalisation, re-grading, training, etc.

The preservation of vegetation on mountain slopes helps to retain a portion of the rainfall and its discharge by slow degrees to streams. De-forested mountains permit of torrents which may cause not only erosion of the soil but may also produce inundations in the plains.

Steps and parapets on the slopes of mountains lessen the velocity of the fall of water thereby helping in a regulated flow in the streams. Similarly the dams and traverses in the course of the streams also help to protect or lessen the force of the flow.

Rough canalisation of streams consists of the collection of stones or mud on either side of the streams so as to confine a water channel within predetermined boundaries. It includes deepening of the bed so as to remove marginal pools and provide a straight and constant flow of water. Work of this kind has a wide application in the removal of breeding places of *anopheles* mosquitoes.

If streams are very crooked and winding it may be necessary to dig new channels and divert water into them. Such training and

canalisation is particularly important in the case of small streams on slopes and hill sides which are often dangerous breeding places. It is not possible to keep up exact and uniform gradients in an unrevetted water course.

If any of the above measures do not have the effect of lessening breeding, it may be necessary to re-grade the whole bed of the river or stream and also to train banks along the whole length.

It has been already stated that large collections of water with rapid flow and quick subsidence are unfavourable to the breeding of mosquitoes. The effect of periodical flooding in the control of mosquito breeding has also been mentioned. This principle can well be utilized in the case of hill streams. One of the common methods of doing so is to build sluices at convenient portions in the stream and allow a periodical weekly flush, which will sweep down all larvæ.

In the case of ravines where the soil is sandy, the best method of affording sub-soil drainage is to provide sub-soil drains which should be at least 3 feet below surface level with a good slope and the size of the drain should be less than 6 inches in diameter. In a ravine, a single line of pipes at each side of the hill-foot intercepts all springs and is often sufficient to dry the whole ravine completely. In wider ravines, several lines of pipes may be necessary. In addition to this sub-soil drainage, it will be a useful measure to level up the bottom of the ravine so as to distribute the storm-water evenly and prevent its cutting into channels. It will also be useful to train steeper portions with grass or turf. The capacity of the pipes should be sufficient to dry ravines completely in a few hours, even in the wettest weather.

Marshes.—In the case of marshes, the main methods of drainage are: (1) Ditching and canalisation, (2) Sub-soil drainage, and (3) Submersion or flooding.

Ditching is the most primitive method. The open earth or *kutcha* ditch is the form of drainage in general use in India. This form of drain usually silts up easily, the sides crumble and the drain itself fails to function. If the surface ditches are properly graded to suitable out-falls and well maintained, they ought to function well and be really effective in diminishing mosquito-breeding. Wherever possible they should have clean cut sloping sides, narrow bottoms and straight courses. The main ditch should be constructed first. Afterwards lateral ditches may be laid out to drain into this main ditch. This form of ditching is usually referred to as " Herring-bone drainage ". Aligning of these ditches should be done by an Engineer.

It will be a very effective improvement if all anti-mosquito ditches are lined especially where excessive erosion takes place or where the cost of *kutcha* drains is exceptionally high. Concrete, stone and mortar, or rubble can be used for this lining. The aligning should be U-shaped with sloping sides. It is not always necessary however to align the whole depth of the ditch. The aligning of the bottom and sides up to three or four inches above normal water line will generally answer the purpose.

In the case of large marshes, circumvallatory or intercepting drains are preferable to cutting channels through or across them. The ordinary method of doing away with swamp or marsh is to dig a ditch around it or along its sides.

In the present generation, drainage has developed into an important agricultural measure for the improvement of crops in excessively moist soils. Such drainage is also of highest value as an anti-mosquito measure. Unclosed agricultural tile pipes are often useful in the drainage of marshy fields. They should be laid with care. It is not applicable to land where there is much silt which would block the pipes. These drains should have a steady gradient. Wherever the fall is less than 2 inches in 100 feet very careful work in laying is essential. Depending on the nature of the soil, the drains should be laid from 2 to 4 feet deep. The system of such sub-soil drainage may consist of mains, sub-mains, laterals, etc. It is of the greatest importance that a suitable outlet for the main be provided in all cases. It is a good rule to restrict the number of mains to the smallest number required and increase the number of laterals. Pipes more than 3 inches in diameter should be used. In laying these drains, work is always begun at the outlet.

It has been long known in agricultural districts in Western countries that the vertical drainage is an effective and economical way of getting rid of pools and marshes. The principle is that of boring a hole through the impervious stratum so that suspended water may escape through the porous layer beneath. There is an element of uncertainty in this vertical drainage; but where a pervious layer is close to the surface, the expense may be less than ditching. The pools should be lined to prevent the blocking up of the escape passage for the water by erosion. When the area to be trained is extensive, it is necessary to make the hole of a considerable size or to sink a number of pools at a large number of places. In many places, it may be necessary to pierce a clay stratum before the porous stratum is reached.

It is a curious but well-known fact that while marshes are completely submerged, they may be non-malarious. If a stratum of

water is made to cover a marshy malarious tract, so long as the water remains at a constant level, there will be a relative improvement. If a swamp can be converted into a lake, it will make a malarious tract healthy. After the flood subsides, unless pools and puddles are left behind, considerable amount of muddy alluvium is deposited on the land and the land itself gains in fertility.

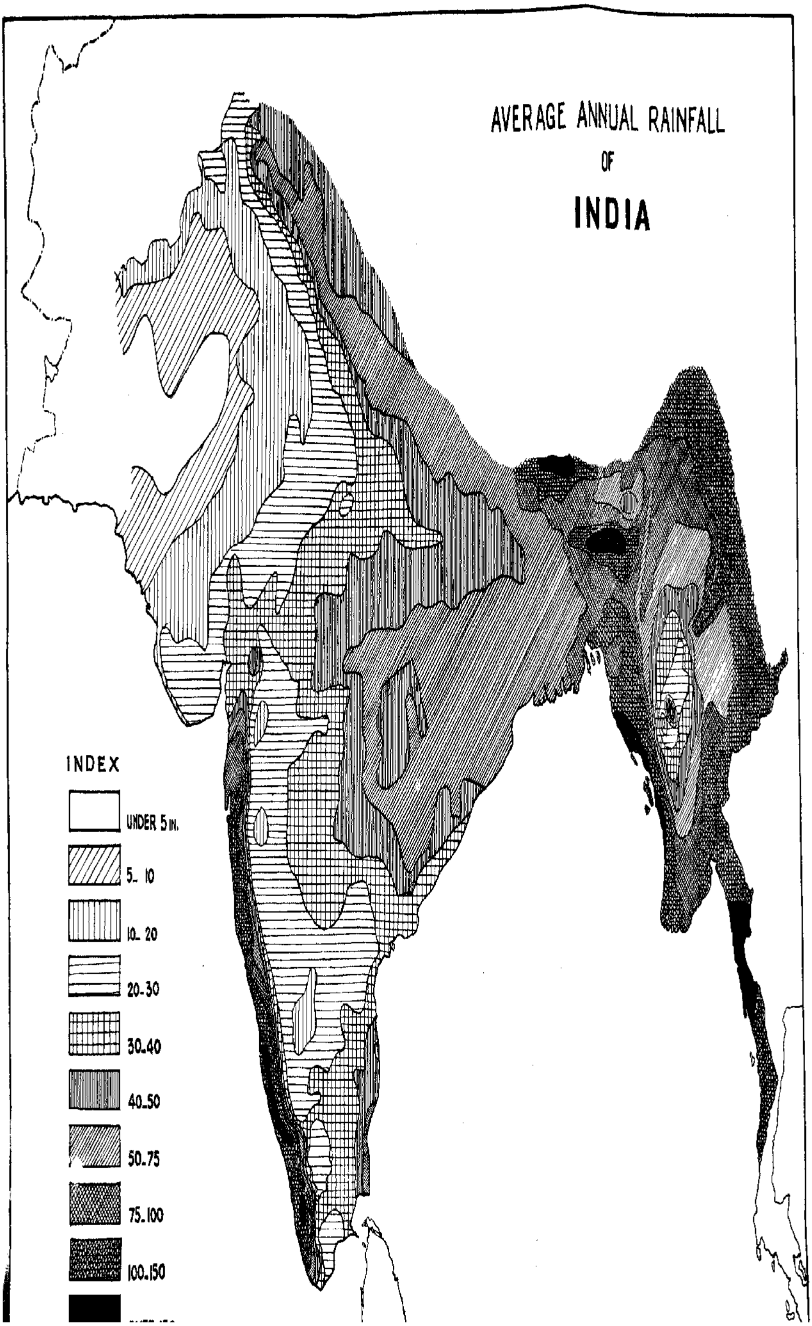
A common cause of marshy formation is the existence of springs at the foot of hills giving rise to high water level. Rainwater collecting between surface land and underlying rock descends towards the bottom of hills and increases size of springs, which collects in holes and forms marshes. For these, a surface drainage which intercepts water is made round the base of the hills; other drainages carry water into the larger ones until they finally discharge into a stream or river.

Wherever irrigation works are carried out or any other works, which will increase the amount of water in the soil are affected, it is necessary simultaneously to carry out adequate sub-soil water drainage in order to remove the effluent. Improvement in the method of distribution of irrigation water to crops is also important. From the malaria point of view, intermittent irrigation is the one which may be best adopted as far as possible.

Other measures.—The general measure for dealing with large sized tanks include clearing the banks free from vegetation, removal of floating debris, fluctuation of water level, introduction of larvicidal fish, etc.

The only other anti-malarial measure that needs mention is the filling up of all points and holes. This is specially necessary in the case of borrow pits breeding *anophelines* very near habitations. Many Engineers look upon the creation of borrow pits as inevitable in forming roads and railway embankments, as the earth required has to be got from somewhere close at hand. If this is accepted, pits in water logged areas should be large and deep so that they do not dry up and kill fish. They should not be allowed to become swampy and must be filled up when situated within half a mile of human habitations.

APPENDIX A.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APPENDIX B

Average monthly and annual rainfall of the Madras Presidency up to the year 1941.

District and station	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.	Highest rainfall.
Vizagapatam (Plains)—														
1 Parvatipur	0·35	0·82	0·93	1·90	3·50	6·52	7·77	9·46	8·33	5·21	2·05	0·71	47·55	5·10
2 Palkonda	0·29	0·62	0·77	1·51	3·26	5·91	7·98	10·01	8·90	5·22	1·52	0·86	46·85	4·01
3 Bobbili	0·24	0·72	1·03	1·44	2·79	5·97	7·08	8·05	7·85	5·51	1·80	0·39	42·96	5·48
4 Salur	0·29	0·44	0·77	1·69	2·91	5·62	6·52	7·83	7·83	7·04	2·30	0·66	43·40	7·52
5 Gajapatinagram	0·39	0·49	0·56	1·01	2·68	5·26	5·66	6·41	7·77	5·99	2·36	0·46	39·04	5·74
6 Chipurupalli	0·24	0·35	0·52	0·88	2·44	4·88	5·33	7·73	7·55	7·04	2·16	0·86	39·98	5·10
7 Vizianagram	0·19	0·62	0·87	0·77	2·75	4·97	5·20	6·99	8·22	7·67	2·52	1·02	41·79	7·99
8 Srungavarapukota	0·41	0·55	0·96	1·47	2·94	5·45	6·01	7·68	8·71	6·50	2·81	0·61	44·10	8·10
9 Chodavaram	0·34	0·44	0·77	1·25	3·23	5·18	5·03	6·12	9·17	7·64	2·73	0·86	42·76	4·43
10 Narasapatam	0·24	0·58	1·07	1·67	3·48	5·28	5·74	5·98	8·82	7·13	2·56	0·58	43·13	8·40
11 Konada	0·35	0·60	0·27	0·61	2·15	4·29	4·06	5·55	6·55	6·48	2·52	0·70	34·13	8·10
12 Bimilipatam	0·32	0·53	0·25	0·46	2·31	3·68	4·20	5·22	6·73	7·76	3·55	0·96	35·97	9·95
13 Waltair (Vizagapatam)	0·46	0·85	0·30	0·71	1·99	4·86	4·49	5·36	6·52	7·07	3·75	0·73	37·09	6·02
14 Balacheruvu	0·27	0·45	0·36	0·66	2·16	4·36	4·25	4·54	6·76	8·55	3·58	1·32	37·26	6·09
15 Anakapalli	0·17	0·33	0·38	0·87	2·21	4·15	4·92	5·17	8·00	6·97	2·84	1·03	37·04	6·00
16 Yellamanchili	0·23	0·48	0·59	0·69	2·47	4·23	4·17	5·03	7·80	7·36	3·13	0·79	36·97	7·21
17 Polavaram	0·16	0·70	0·26	0·79	1·74	4·73	3·95	4·91	4·88	5·43	3·14	0·52	31·21	8·20
18 Ichchapuram	0·28	0·65	0·38	1·14	2·14	5·05	6·63	7·36	7·84	8·78	3·46	0·75	44·46	10·90
19 Chicacole	0·14	0·41	0·35	0·60	2·38	4·01	5·60	6·89	7·23	7·19	2·46	1·32	38·58	4·80
20 Narasannapeta	0·08	0·30	0·49	0·67	2·65	4·19	6·26	6·66	7·46	6·65	2·32	0·44	38·17	5·40
21 Patapatnam	0·22	0·70	0·78	1·60	3·51	6·40	8·36	9·55	9·61	6·52	1·90	0·88	50·03	3·97
22 Tekkali	0·21	0·46	0·50	0·76	2·15	4·54	6·87	7·79	9·03	7·50	2·43	1·05	43·29	5·95
23 Calingapatam	0·29	0·51	0·42	0·89	2·55	4·73	5·28	7·92	7·38	7·95	3·90	0·65	42·47	7·41
24 Pundi	0·11	0·50	0·52	0·61	1·66	3·99	5·73	5·84	7·00	6·62	2·90	1·04	36·52	7·41
25 Sompeta	0·27	0·93	0·73	1·41	2·48	4·75	6·69	7·03	8·68	9·39	3·58	0·97	46·91	5·18
Average	**0·26**	**0·56**	**0·59**	**1·04**	**2·58**	**4·92**	**5·67**	**6·95**	**7·77**	**7·01**	**2·73**	**0·81**	**40·80**	..
East Godavari (Plains)—														
1 Tuni	0·21	0·35	0·45	0·82	2·11	4·51	5·28	5·02	7·49	6·45	2·40	0·81	35·90	6·85
2 Pithapuram	0·17	0·21	0·29	0·53	1·68	4·44	5·57	5·54	6·17	6·94	2·82	0·46	34·82	8·50
3 Prattipadu	0·15	0·36	0·50	0·99	2·15	4·87	6·35	5·59	7·32	6·42	1·94	0·34	36·98	11·56
4 Peddapuram	0·15	0·29	0·37	0·67	1·99	4·88	6·39	6·30	6·51	6·36	2·92	0·40	37·23	9·38
5 Rajahmundry	0·22	0·22	0·43	0·72	2·45	5·61	7·20	7·19	7·11	6·47	2·13	0·16	39·91	4·36
6 Cocanada	0·19	0·32	0·46	0·56	1·54	4·81	5·83	5·49	5·75	7·85	5·42	0·87	39·09	11·10
7 Ramachandrapur	0·18	0·22	0·41	0·61	1·89	5·24	6·61	6·36	7·04	7·99	4·07	0·11	41·26	8·60
8 Alamuru	0·08	0·28	0·33	0·75	1·86	5·39	6·71	7·81	6·70	7·03	3·19	0·29	39·42	9·62
9 Kothapeta	0·04	0·23	0·35	0·64	1·76	6·05	6·98	6·73	6·48	7·64	3·92	0·46	41·20	5·30

Average monthly and annual rainfall of the Madras Presidency up to the year 1941—cont.

District and station.	January.	February.	March.	April	May.	June.	July.	August.	September.	October.	November.	December.	Annual.	Highest rainfall.
East Godavari (Plains)—*cont.*														
10 Amalapuram	0·24	0·29	0·35	0·46	1·84	5·67	6·43	6·55	7·44	9·76	5·02	0·66	44·79	6·78
11 Razole	0·17	0·21	0·13	0·34	1·14	5·29	6·24	6·37	7·67	9·71	4·00	0·24	42·62	7·94
12 Mummidivaram	0·22	0·45	0·46	0·68	1·48	5·78	5·57	6·44	6·46	8·57	5·06	1·12	41·79	8·80
13 Coringa	0·21	0·24	0·29	0·56	1·63	4·97	5·74	5·50	6·34	10·61	5·73	0·27	42·59	6·20
14 Biccavole	0·90	0·07	0·24	0·62	3·55	7·83	6·52	6·76	6·61	6·85	5·19	..	45·18	6·30
Average	**0·22**	**0·27**	**0·36**	**0·64**	**1·96**	**5·36**	**6·26**	**6·19**	**6·81**	**7·82**	**3·86**	**0·27**	**40·25**	..
East Godavari Agency—														
1 Nugur	0·27	0·97	0·80	1·21	1·96	9·54	16·79	13·58	10·57	4·70	1·29	0·13	61·81	7·03
2 Bhadrachalam	0·14	0·36	0·47	1·13	1·75	6·56	10·19	10·45	7·55	2·82	0·94	0·22	42·58	5·01
3 Polavaram	0·25	0·34	0·50	1·64	2·64	6·46	8·09	7·63	7·27	6·17	2·20	0·20	44·29	10·20
4 Chodavaram	0·31	0·33	0·45	1·33	2·23	5·70	8·48	7·43	8·63	6·70	2·24	0·32	44·16	10·15
5 Yellavaram	0·35	0·48	0·76	3·33	3·26	6·29	8·81	9·47	10·15	6·81	2·30	0·16	52·17	4·62
Average	**0·26**	**0·49**	**0·59**	**1·73**	**2·39**	**6·91**	**10·65**	**9·71**	**8·83**	**5·44**	**1·79**	**0·21**	**49·00**	..
West Godavari—														
1 Ellore	0·25	0·22	0·41	0·49	1·38	4·53	6·32	6·63	7·17	5·83	1·98	0·29	35·56	5·75
2 Chintalapudi	0·23	0·20	0·43	0·94	1·80	5·87	8·95	8·05	7·17	4·74	1·52	0·29	40·19	5·23
3 Kovvur	0·13	0·35	0·36	0·98	2·31	5·42	7·29	6·72	7·37	5·13	1·80	0·26	38·12	8·25
4 Tadepalligudem	0·14	0·25	0·35	0·57	1·64	5·32	6·76	6·73	6·78	5·98	2·39	0·22	37·08	8·38
5 Tanuku	0·07	0·16	0·35	0·60	1·73	4·97	6·77	6·41	6·74	6·59	3·04	0·26	37·69	7·65
6 Penugonda	0·22	0·28	0·38	0·13	1·71	7·37	7·40	6·38	8·22	7·52	5·21	0·03	44·85	4·85
7 Bhimavaram	0·14	0·23	0·19	0·42	1·66	4·94	6·08	6·58	6·21	7·03	3·52	0·40	37·40	10·35
8 Narasapuram	0·15	0·17	0·26	0·32	1·35	5·21	6·38	7·10	7·34	8·84	5·09	0·27	42·48	10·40
Average	**0·17**	**0·23**	**0·34**	**0·56**	**1·70**	**5·46**	**6·99**	**6·83**	**7·12**	**6·45**	**3·07**	**0·25**	**39·17**	..
Kistna—														
1 Tiruvur	0·21	0·17	0·49	0·82	1·60	5·23	9·77	7·72	6·00	3·98	1·42	0·24	37·65	7·02
2 Jaggayyapeta	0·28	0·16	0·34	0·99	0·84	4·32	6·01	5·92	5·89	4·18	1·48	0·23	30·59	3·00
3 Nandigama	0·40	0·22	0·44	0·62	1·50	4·22	6·63	6·39	6·57	3·84	1·88	0·27	32·98	10·13
4 Bezwada	0·27	0·25	0·40	0·55	1·66	5·05	6·39	6·33	6·04	5·20	2·61	0·35	35·10	9·48
5 Nuzvid	1·38	0·22	1·14	0·66	2·98	7·07	6·33	7·76	6·35	6·27	2·83	0·09	43·08	5·67
6 Gudivada	0·24	0·18	0·46	0·70	1·77	3·94	6·00	6·18	5·34	6·37	3·13	0·34	34·65	5·00
7 Bandar	0·23	0·42	0·28	0·62	1·34	4·51	6·44	6·91	6·20	8·10	5·67	0·87	41·59	14·00
8 Avanigadda	0·52	0·67	0·25	0·86	1·35	3·64	5·68	7·26	5·97	8·19	4·79	0·66	39·84	12·90
9 Kaikalur	0·24	0·28	0·22	0·47	1·48	4·59	6·57	6·89	5·75	6·03	2·52	0·33	35·32	9·48

10 Gannavaram	0·22	0·26	0·48	0·63	1·31	5·05	7·15	6·63	6·45	4·67	2·64	0·33	35·82	5·20
11 Pandraka	0·18	0·40	0·28	0·69	1·20	4·62	6·25	6·50	5·50	7·03	2·99	0·31	35·95	10·00
12 Manginapudi	0·20	0·44	0·33	0·68	1·17	4·47	7·40	6·16	5·68	7·92	3·70	0·62	38·77	11·70
Average ..	**0·36**	**0·30**	**0·43**	**0·69**	**1·52**	**4·73**	**6·72**	**6·72**	**5·93**	**5·96**	**2·97**	**0·39**	**36·77**	..
Guntur—														
1 Guntur	0·35	0·28	0·65	0·54	1·93	4·28	5·25	5·61	5·52	5·30	2·82	0·48	33·01	7·23
2 Mangalagiri	0·33	0·30	0·32	1·04	1·85	5·29	6·14	6·18	5·19	4·03	2·64	0·39	33·70	5·70
3 Sattenapalle	0·53	0·38	0·40	0·77	1·52	3·92	4·50	4·90	5·55	4·37	2·61	0·23	29·68	5·40
4 Tenali	0·34	0·25	0·35	0·81	2·08	4·74	6·24	6·70	6·37	5·44	3·12	0·46	36·99	6·70
5 Repalle	0·32	0·29	0·39	0·42	1·34	3·87	5·39	6·51	6·05	8·24	4·38	0·52	37·72	9·15
6 Ponnur	0·23	0·45	0·27	0·47	1·36	4·02	5·21	6·19	5·64	5·95	3·04	0·39	33·22	7·70
7 Bapatla	0·27	0·16	0·33	0·31	1·72	3·70	4·69	6·57	6·46	7·08	4·46	0·50	36·25	6·80
8 Santaravuru	0·45	0·01	0·35	0·50	1·15	2·79	4·95	5·09	6·27	6·43	3·73	0·74	32·46	8·10
9 Chinaganjam	0·39	0·36	0·20	0·40	1·25	2·45	3·63	4·43	4·93	6·78	5·09	0·83	30·74	7·90
10 Gurazala	0·23	0·14	0·41	0·40	1·38	3·35	4·43	5·31	6·25	4·16	1·96	0·37	28·39	3·30
11 Macherla	0·29	0·18	0·48	0·79	1·62	2·70	3·98	3·84	4·89	3·64	1·56	0·63	24·60	3·54
12 Narasaraopet	0·35	0·21	0·47	0·68	1·74	3·31	4·32	4·70	5·15	5·22	2·80	0·40	29·35	3·39
13 Vinukonda	0·28	0·15	0·36	0·72	1'45	2·38	3·06	3·77	4·96	5·11	3·05	0·94	26·23	3·40
14 Ongole	0·45	0·16	0·24	0·40	1·26	1·87	3·15	3·84	5·51	9·03	6·77	1·09	33·77	4·63
15 Addanki	0·30	0·18	0·23	0·44	1·58	2·50	3·15	4·10	5·58	5·80	3·81	0·86	28·53	7·10
16 Kanuparti	0·50	0·25	0·21	0·49	1·28	2·09	3·64	4·40	5·50	8·39	6·69	0·86	34·30	11·30
Average ..	**0·35**	**0·23**	**0·35**	**0·57**	**1·53**	**3·33**	**4·48**	**5·14**	**5·62**	**5·94**	**3·66**	**0·61**	**31·81**	..
Nellore—														
1 Nellore	1·68	0·12	0·15	0·36	0·83	1·28	2·75	3·27	4·75	8·36	11·24	3·19	37·98	14·05
2 Gudur	1·30	0·24	0·16	0·20	1·05	1·28	1·99	3·07	3·76	8·68	10·37	3·37	35·56	9·18
3 Sulurpet	1·40	0·18	0·16	0·37	1·02	1·91	2·87	3·42	4·53	10·39	12·01	5·08	43·34	8·72
4 Venkatagiri	1·56	0·39	0·29	0·30	1·48	1·57	2·61	3·14	3·44	8·68	10·80	4·17	38·43	6·40
5 Rapur	1·68	0·30	0·42	0·51	1·65	1·45	2·50	2·99	3·66	9·31	10·51	4·01	38·99	7·00
6 Atmakur	0·93	0·23	0·32	0·36	1·35	1·05	2·00	2·26	3·57	7·73	8·11	2·41	30·32	7·95
7 Udayagiri	1·05	0·28	0·52	0·80	1·56	1·26	2·28	2·38	3·56	7·64	7·20	2·11	30·62	8·50
8 Kanigiri	0·53	0·19	0·22	0·55	1·62	1·68	2·53	2·35	4·03	6·08	4·52	1·20	25·50	5·10
9 Podili	0·47	0·25	0·42	0·54	1·42	1·56	2·26	2·47	4·76	5·93	4·38	1·17	25·63	5·25
10 Darsi	0·39	0·17	0·44	0·53	1·49	2·22	2·54	2·95	4·34	5·21	3·70	1·16	25·14	2·50
11 Kandukur	0·74	0·17	0·20	0·36	1·38	1·58	2·57	3·04	5·02	8·70	7·85	1·79	33·41	10·98
12 Kavali	0·96	0·19	0·17	0·27	1·09	1·50	2·33	3·02	4·52	10·50	10·68	2·77	38·30	12·35
13 Iskapalle	0·95	0·20	0·19	0·25	0·97	1·48	2·22	3·36	4·76	10·74	11·06	2·50	38·68	10·30
14 Krishnapatam	1·36	0·21	0·16	0·34	0·95	1·67	2·65	3·61	3·80	10·76	11·08	3·30	39·89	10·27
15 Pakala	0·51	0·11	0·16	0·22	1·24	1·52	2·25	3·48	4·48	19·09	7·82	1·74	32·62	12·00
16 Tada	1·36	0·37	0·20	0·37	1·40	2·08	3·04	3·78	4·30	10·01	12·49	4·12	43·52	11·26
Average ..	**1·03**	**0·23**	**0·26**	**0·39**	**1·31**	**1·57**	**2·46**	**2·15**	**2·61**	**8·71**	**9·02**	**2·76**	**34·93**	..
Madras—														
1 Madras	1·43	0·32	0·19	0·53	1·07	1·89	3·94	4·64	4·90	11·72	14·25	5·81	50·78	7·34

Average monthly and annual rainfall of the Madras Presidency up to the year **1941**—cont.

District and station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.	Highest rainfall.
Chingleput—														
1 Attipet	1·63	0·30	0·08	0·34	0·81	1·25	2·44	3·42	4·45	12·61	12·83	4·53	44·69	10·93
2 Ponneri	1·25	0·57	0·15	0·39	1·55	1·70	3·28	4·64	5·07	10·74	14·00	4·72	48·06	8·40
3 Satiavedu	1·42	0·52	0·30	0·35	1·81	2·20	3·42	4·21	4·98	9·13	11·45	4·49	44·28	7·50
4 Tiruvallur	1·10	0·46	0·31	0·49	1·66	2·19	3·66	4·91	5·34	7·60	10·04	4·07	41·83	8·15
5 Conjeeveram	0·72	0·32	0·17	0·62	2·06	2·64	4·46	5·92	5·98	7·53	9·35	3·98	43·75	6·85
6 Sriperumbudur	1·01	0·24	0·11	0·45	1·33	2·00	3·70	5·18	5·35	8·38	10·29	4·72	42·76	5·03
7 Poonamallee	1·28	0·19	0·20	0·45	0·95	1·76	3·94	4·67	4·87	10·57	13·28	5·85	48·01	6·68
8 Saidapet	1·22	0·43	0·22	0·46	1·49	1·89	3·71	4·82	5·53	11·72	14·73	5·48	51·70	7·29
9 Covelong	1·58	0·53	0·07	0·60	1·29	1·38	3·92	5·51	5·47	11·65	14·21	5·59	51·80	6·00
10 Chingleput	0·80	0·38	0·17	0·54	1·56	2·41	4·13	5·76	5·79	9·31	11·51	4·84	47·20	5·37
11 Cheyyur	1·15	0·53	0·06	0·72	0·87	0·95	3·18	5·72	5·29	10·32	15·49	5·50	49·78	7·83
12 Madurantakam	0·81	0·35	0·17	0·44	2·21	1·97	4·00	5·81	6·47	8·61	11·82	4·99	47·65	5·87
13 Uttiramerur	0·78	0·34	0·17	0·63	1·49	2·46	4·24	5·90	6·19	7·75	10·01	4·68	44·64	6·35
14 Voyalur	1·62	0·26	0·08	0·34	0·95	1·42	2·88	3·47	4·08	11·64	13·20	4·70	44·68	..
Average ..	**1·17**	**0·39**	**0·16**	**0·49**	**1·43**	**1·87**	**3·64**	**4·99**	**5·34**	**9·83**	**12·30**	**4·87**	**46·50**	..
Chittoor—														
1 Tiruttani	1·03	0·15	0·32	0·60	2·21	2·50	3·53	5·27	5·50	6·66	8·15	2·97	38·98	6·70
2 Puttur	1·01	0·13	0·25	0·54	2·16	2·89	3·76	5·51	5·16	6·76	7·92	2·84	38·93	6·51
3 Kalahasti	1·96	0·23	0·18	0·35	1·54	2·02	2·91	3·42	4·03	8·96	12·48	4·61	42·69	7·11
4 Tirupati	1·13	0·21	0·22	0·49	2·01	1·95	2·60	4·09	4·90	6·06	7·78	2·72	34·16	4·94
5 Chandragiri	0·79	0·20	0·24	0·67	1·89	2·34	2·92	4·32	4·93	5·52	6·52	2·13	32·47	4·68
6 Pakala	1·74	0·15	0·51	1·02	2·86	2·20	3·43	5·23	5·21	5·05	6·32	1·02	34·84	6·00
7 Chittoor	0·77	0·27	0·32	0·74	2·61	2·49	3·35	5·04	6·91	6·60	5·45	1·88	36·43	5·17
8 Venkatagirikota	0·46	0·19	0·36	0·90	3·12	1·94	2·87	4·21	5·82	5·42	4·02	1·26	30·57	4·27
9 Palmaner	0·59	0·20	0·37	0·93	2·83	2·68	3·19	4·46	6·86	6·78	4·87	1·45	35·27	4·46
10 Punganur	0·30	0·22	0·38	0·86	2·46	1·87	2·87	3·81	4·93	5·15	3·93	0·89	27·67	2·48
11 Madanapalle	0·46	0·18	0·51	0·93	2·60	2·12	2·47	3·29	4·80	5·47	4·13	0·99	27·95	4·28
12 Vayalpad	0·54	0·25	0·35	0·70	2·36	1·99	2·93	3·44	4·83	5·10	4·19	1·13	27·81	4·23
13 Piler	0·68	0·16	0·23	0·65	1·80	1·98	2·65	3·71	5·41	4·78	4·34	1·21	27·60	4·00
14 Kuppam	0·32	0·25	0·38	1·13	3·87	1·97	2·78	4·19	6·51	5·54	3·47	0·99	31·40	3·95
Average ..	**0·84**	**0·20**	**0·33**	**0·75**	**2·45**	**2 22**	**3·02**	**4·29**	**5·42**	**5·99**	**5·97**	**1·83**	**33·20**	..
North Arcot—														
1 Vellore	1·49	0·29	0·24	0·95	2·30	2·35	5·31	6·28	7·27	6·34	6·88	2·71	42·41	8·17
2 Arni	0·77	0·21	0·20	0·68	2·19	2·25	3·52	6·06	6·81	6·95	6·87	2·91	39·42	7·13
3 Polur	0·73	0·44	0·27	0·61	2·97	2·10	3·00	5·96	7·82	7·16	6·09	2·87	40·02	6·40
4 Tiruvannamalai	0·90	0·52	0·44	0·77	3·25	1·70	3·02	5·38	6·73	7·17	6·62	2·58	39·08	4·75

5 Chengam	0·81	0·35	0·70	0·89	3·08	1·77	3·05	5·41	6·57	7·63	5·39	2·08	37·73	4·30
6 Wandiwash	0·67	0·36	0·26	0·66	2·33	2·82	4·33	6·24	6·86	7·52	9·14	3·87	45·06	7·30
7 Cheyyar	0·86	0·38	0·16	0·74	1·90	1·52	4·16	6·15	7·59	6·36	7·70	3·81	41·33	4·71
8 Walajah	0·61	0·30	0·43	0·51	2·33	3·02	3·88	5·78	6·65	6·57	6·98	2·89	39·95	6·00
9 Arkonam	0·98	0·30	0·26	0·71	1·77	2·19	3·71	4·68	5·54	6·37	8·58	3·58	38·67	6·35
10 Gudiyattam	0·54	0·28	0·32	0·75	2·54	2·52	3·56	4·78	6·95	6·40	5·04	1·84	35·52	6·04
11 Tiruppattur	0·28	0·22	0·45	1·15	4·09	2·46	3·55	5·34	7·51	5·50	8·46	1·05	35·06	3·07
12 Sholinghur	1·58	0·05	0·38	0·63	1·98	1·40	4·31	5·58	5·79	5·97	6·98	2·13	36·78	5·60
13 Ambur	0·89	0·09	0·24	0·78	2·54	2·00	3·00	4·10	6·42	4·05	4·22	1·45	29·78	4·05
14 Vanivambadi	0·50	0·16	0·27	0·87	3·42	2·15	3·02	4·75	6·89	2·99	3·67	1·44	30·13	3·00
Average ..	**0·83**	**0·28**	**0·33**	**0·76**	**2·62**	**2·16**	**3·67**	**5·46**	**6·81**	**8·21**	**6·26**	**2·52**	**37·96**	..
South Arcot—														
1 Gingee	1·00	0·28	0·26	0·82	2·03	2·13	3·41	6·07	7·10	7·02	7·57	3·68	41·35	9·20
2 Tindivanam	0·88	0·51	0·20	0·79	1·96	1·78	3·48	6·01	6·98	8·15	9·42	4·37	44·53	7·75
3 Mercanam	0·93	0·34	0·14	0·67	1·00	1·39	3·08	6·20	6·04	9·90	14·79	6·10	50·58	5·37
4 Vanur	0·94	0·40	0·13	0·52	1·24	1·32	3·10	5·21	5·73	9·12	11·44	6·07	45·22	9·70
5 Villupuram	0·96	0·41	0·18	0·76	1·89	1·87	3·51	5·70	6·33	8·33	8·56	4·34	42·84	6·80
6 Panruti	1·10	0·58	0·15	0·74	1·38	1·91	3·52	5·62	6·24	9·48	11·02	5·64	47·38	9·84
7 Cuddalore	1·56	0·89	0·17	0·60	0·73	1·54	3·11	4·97	6·06	11·00	15·08	7·23	52·94	9·23
8 Kurinjipadi	2·04	0·72	0·22	0·49	1·66	1·51	3·73	5·51	6·11	9·05	14·34	5·92	51·30	7·40
9 Porto Novo	1·49	0·86	0·24	0·90	1·14	1·15	3·22	4·18	6·34	12·08	16·43	7·62	55·65	10·01
10 Chidambaram	1·20	0·74	0·22	0·60	1·77	1·70	2·89	5·58	5·72	10·56	15·60	8·16	54·74	8·71
11 Mannargudi	1·20	0·61	0·13	0·81	1·76	1·56	2·28	5·11	5·76	8·80	13·40	7·02	48·44	10·44
12 Srimushnam	1·80	0·54	0·19	1·07	2·39	1·58	2·86	5·60	5·83	7·22	10·32	4·36	43·76	7·98
13 Tittagudi	0·90	0·59	0·23	0·98	2·95	1·70	3·10	5·19	6·30	7·11	7·39	3·86	40·30	7·97
14 Vriddhachalam	0·76	0·49	0·27	0·81	2·08	1·76	3·00	5·84	5·99	7·56	8·27	4·20	41·03	5·40
15 Kallakkurichi	1·00	0·61	0·33	1·11	3·24	1·91	3·08	5·33	5·92	7·54	6·74	3·08	39·89	6·25
16 Ulundurpet	0·97	0·61	0·16	0·91	2·54	2·13	3·30	5·44	5·83	7·58	8·28	4·00	41·75	5·99
17 Tirukkoyillur	0·68	0·49	0·19	0·74	2·45	2·18	3·58	5·63	7·12	7·31	6·91	2·95	40·23	5·70
Average ..	**1·12**	**0·56**	**0·20**	**0·79**	**1·93**	**1·72**	**3·19**	**5·50**	**6·28**	**6·82**	**10·93**	**5·23**	**46·01**	..
Tanjore—														
1 Shiyali	1·31	0·58	0·28	0·58	1·55	1·57	2·53	4·72	4·73	10·39	16·72	8·96	53·92	8·62
2 Neidavasal	1·38	0·63	0·27	0·67	0·84	1·14	1·59	4·22	4·37	11·05	18·61	7·75	52·52	8·72
3 Tranquebar	1·33	0·49	0·20	0·62	1·63	1·11	1·93	3·93	3·72	10·90	16·18	9·57	51·61	14·95
4 Mayavaram	1·47	0·58	0·33	0·74	2·25	1·29	2·32	4·89	4·16	8·79	14·67	8·28	49·77	8·90
5 Kumbakonam	1·06	0·61	0·33	0·80	2·58	2·20	2·09	4·93	5·51	7·51	9·96	5·79	43·01	8·15
6 Papanasam	1·99	0·36	0·23	0·82	2·75	1·37	2·98	4·44	4·45	5·85	14·04	4·73	44·01	7·39
7 Valangiman	1·36	0·39	0·09	0·71	2·37	1·65	1·88	5·43	5·41	6·59	11·70	5·35	42·93	6·42
8 Kodavasal	1·50	0·64	0·20	0·93	2·36	1·34	1·76	4·42	5·55	7·12	12·54	6·93	45·19	4·95
9 Nannilam	1·35	0·69	0·45	0·81	1·95	0·93	2·32	3·60	4·75	7·56	13·75	8·46	46·62	9·44
10 Tiruvarur	1·58	0·76	0·46	0·96	2·05	1·52	1·81	3·93	4·34	8·57	13·62	9·73	49·33	9·69
11 Negapatam	1·68	0·63	0·34	0·57	1·61	1·30	1·89	3·59	3·77	10·48	17·72	11·40	54·98	12·18
12 Tiruppundi	2·43	0·59	0·37	0·72	1·64	1·22	1·69	3·37	4·38	9·78	19·42	11·07	56·62	10·75
13 Vedaranniyam	1·79	0·47	0·53	1·47	1·61	1·08	1·70	3·18	4·07	10·18	18·06	10·21	54·35	12·52
14 Tiruturaipundi	1·27	0·73	0·43	1·07	1·76	1·21	1·96	4·05	4·33	7·74	13·17	8·18	45·90	8·85

Average monthly and annual rainfall of the Madras Presidency up to the year **1941**—cont.

District and station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.	Highest rainfall.
Tanjore—*cont.*														
15 **Muttupet**	1·26	0·67	0·62	1·65	2·16	1·41	1·68	4·28	4·46	8·07	10·31	7·44	44·01	7·04
16 **Mannargudi**	1·13	0·72	0·35	1·12	2·12	1·70	2·27	5·02	5·59	7·74	10·33	6·91	45·00	9·50
17 **Nidamangalam**	1·20	0·60	0·33	1·01	2·76	1·54	2·52	5·02	5·40	7·30	10·24	6·75	44·67	8·00
18 **Tiruvadi**	1·01	0·49	0·22	1·02	2·50	1·57	1·82	4·43	5·30	6·39	7·52	4·18	36·54	6·29
19 **Tirukkattupalli**	1·61	0·52	0·24	1·05	2·45	1·25	1·52	4·77	5·65	5·86	8·46	3·25	36·63	4·37
20 **Tanjore**	0·96	0·49	0·33	1·08	2·17	1·81	1·97	4·36	5·84	6·20	7·40	4·56	37·17	6·83
21 **Vallam**	0·90	0·53	0·33	1·00	2·63	1·85	2·10	5·07	5·90	6·79	6·92	4·67	38·78	5·63
22 **Pattukkottai**	1·08	0·65	0·51	1·56	2·09	1·70	2·12	4·58	3·99	7·03	8·82	6·12	40·25	8·25
23 **Adirampatnam**	1·66	0·52	0·33	1·07	1·54	1·12	2·56	4·08	4·40	7·20	10·12	4·96	39·56	8·00
24 **Kattumavadi**	1·20	0·70	0·47	1·57	1·61	0·95	1·71	3·24	3·81	7·25	8·21	5·37	36·09	4·54
25 **Arantangi**	0·89	0·38	0·36	1·29	2·13	1·40	2·09	4·13	4·10	6·83	6·76	4·20	34·65	7·67
26 **Grand Anicut**	Excluded.		..	..	..	..	..	..	..	..	..	..	..	9·56
Average ..	**1·37**	**0·59**	**0·34**	**1·00**	**2·06**	**1·42**	**2·03**	**0·08**	**4·72**	**7·94**	**12·19**	**6·98**	**44·94**	..
Trichinopoly—														
1 **Musiri**	0·51	0·30	0·35	1·40	3·61	1·24	2·29	2·91	4·50	7·49	5·14	1·89	30·63	5·14
2 **Turaiyur**	0·52	0·30	0·61	1·44	4·24	1·36	1·70	3·28	5·75	6·68	5·00	2·04	32·92	8·83
3 **Uppiliyapuram**	1·26	0·26	0·65	1·03	4·66	1·31	2·51	3·69	5·10	6·85	5·73	1·84	34·80	3·18
4 **Settikulam**	1·14	0·64	0·62	1·16	4·08	1·55	2·98	4·17	6·52	6·54	6·89	2·87	39·16	5·40
5 **Perambalur**	0·83	0·56	0·45	1·27	3·68	1·75	2·16	4·69	5·80	7·80	7·04	3·21	39·24	6·04
6 **Ariyalur**	0·78	0·54	0·24	1·01	3·07	1·45	2·53	4·81	6·10	7·01	7·24	3·88	38·70	12·96
7 **Jayankondan**	1·15	0·65	0·32	1·13	2·52	1·45	2·64	5·13	6·06	6·99	9·64	5·48	43·16	8·61
8 **Lalgudi**	0·70	0·42	0·27	1·30	3·02	1·14	1·32	3·93	5·52	6·56	6·22	2·99	33·39	6·96
9 **Trichinopoly**	0·68	0·56	0·43	1·65	3·14	1·41	1·57	3·83	4·83	6·90	5·57	2·61	33·18	11·74
10 **Kulitalai**	0·49	0·28	0·36	1·36	3·85	1·14	1·25	2·60	4·21	6·82	4·97	1·89	29·22	6·06
11 **Marungapuri**	0·78	0·34	0·52	1·71	3·23	1·43	1·66	3·19	4·86	7·15	5·63	2·86	33·36	6·45
12 **Iluppur**	0·68	0·31	0·27	1·34	2·71	1·64	1·95	4·55	5·29	6·46	4·91	2·99	33·10	9·47
13 **Manapparai**	1·40	0·27	0·41	1·37	4·02	1·67	2·25	4·05	4·81	6·96	5·80	2·58	35·59	8·88
14 **Karur**	0·23	0·18	0·25	1·33	3·63	1·17	1·10	3·02	3·97	6·10	3·92	1·30	26·20	5·71
15 **Aravakurichi**	0·57	0·35	0·50	1·48	3·57	1·03	0·81	1·45	3·44	5·98	4·01	1·70	24·89	7·35
16 **Thathiengarpet**	0·94	0·24	0·66	1·73	4·50	1·08	1·41	3·35	6·04	6·06	5·05	1·59	32·65	5·49
Average ..	**0·79**	**0·56**	**0·43**	**1·65**	**8·14**	**1·41**	**1·57**	**3·83**	**4·83**	**6·90**	**5·80**	**2·61**	**33·78**	..
Pudukkottai State—														
1 **Pudukkottai**	0·70	0·46	0·51	1·41	2·73	2·14	3·08	5·98	5·70	6·18	6·16	3·60	38·65	10·73
2 **Alangudi**	0·92	0·52	0·49	1·20	2·36	2·00	3·00	4·98	6·09	5·78	7·08	3·54	37·99	11·20
3 **Karambakkudi**	0·79	0·52	0·42	1·07	1·59	1·23	2·09	3·72	4·26	4·24	6·37	3·56	29·86	7·35

4 Tirumayam	0·96	0·56	0·48	1·46	2·64	2·06	2·71	5·59	6·30	6·57	5·88	2·92	38·13	8·11
5 Keelanilai	0·78	0·38	0·30	1·41	2·17	1·33	2·43	4·34	4·82	6·06	6·45	3·57	33·54	10·70
6 Kolattur	0·53	0·31	0·21	1·22	2·27	1·48	1·87	3·26	5·16	5·09	5·18	2·36	28·94	11·20
7 Viralimalai	0·92	0·39	0·45	1·18	2·86	1·33	1·61	3·25	5·70	7·56	5·30	2·05	32·70	7·05
8 Odayalipatti	0·89	0·51	0·39	1·42	2·32	1·76	2·19	4·17	6·10	5·85	5·35	2·80	33·75	13·77
9 Annavasal	0·67	0·30	0·29	1·22	3·12	1·77	2·09	3·95	6·22	6·07	5·26	2·55	33·51	6·74
10 Ponnamaravati	0·82	0·44	0·52	1·70	2·58	1·91	2·68	5·04	6·20	6·49	5·47	2·59	36·44	8·32
11 Adanakkottai	0·99	0·50	0·37	1·45	2·26	1·87	2·37	4·70	5·47	5·51	6·11	3·63	35·23	5·20
Average ..	0·69	0·38	0·34	1·14	2·69	1·38	2·09	3·77	4·39	5·02	4·62	2·37	27·55	..
Madura—														
1 Natham	1·18	0·18	0·60	1·13	3·91	2·05	2·60	3·47	5·73	6·33	6·88	2·70	36·76	7·51
2 Melur	0·62	0·30	0·55	1·70	3·16	2·16	2·31	4·98	5·51	8·13	5·11	2·73	37·35	7·57
3 Sholavaram	0·79	0·89	0·37	1·44	3·00	1·37	1·87	2·49	4·82	7·58	6·03	1·54	31·69	3·20
4 Madura	0·60	0·36	0·51	2·03	2·89	1·37	1·92	4·25	5·11	7·82	4·95	1·77	33·58	3·27
5 Peraiyur	0·78	0·74	0·68	2·68	3·27	1·20	1·35	2·79	4·01	7·22	6·40	2·21	33·33	4·50
6 Tirumangalam	0·53	0·85	0·68	1·14	3·08	1·21	1·55	3·56	4·33	7·92	5·16	1·82	32·33	3·13
7 Usilampatti	0·83	0·56	0·88	2·39	3·30	0·85	0·92	2·46	3·95	8·48	6·55	2·12	33·29	2·30
8 Uttamapalaiyam	0·58	0·73	0·75	2·31	2·60	1·58	1·62	1·28	1·70	7·17	6·61	2·11	20·04	2·62
9 Bodinayakkanur	0·91	0·74	1·60	2·90	2·49	1·30	1·04	1·53	2·00	6·67	5·58	1·69	28·45	3·45
10 Periyakulam	1·13	0·98	1·82	2·97	2·99	0·97	0·95	1·85	2·67	7·16	5·13	1·73	30·35	4·27
11 Nilakkottai	0·61	0·38	0·60	2·03	3·03	0·83	1·05	2·31	3·89	7·00	4·76	1·62	28·11	4·12
12 Dindigul	0·73	0·45	0·62	1·96	3·03	1·84	1·36	2·65	3·62	6·27	5·40	2·60	30·53	7·23
13 Vedasandur	0·66	0·41	0·60	1·87	3·40	1·17	0·64	1·67	2·94	6·38	4·36	2·31	26·41	5·81
14 Chatrapatti	1·35	0·35	0·29	1·32	3·17	1·45	1·66	1·66	2·54	9·01	7·55	2·67	33·02	8·96
15 Palni	0·52	0·41	0·60	1·49	2·86	1·09	0·74	1·19	2·07	6·86	6·13	2·52	26·48	6·21
16 Kodaikanal	2·88	1·41	2·03	4·25	6·02	4·06	5·02	6·99	7·25	9·68	8·17	4·42	62·18	..
Average ..	0·92	0·55	0·82	2·11	3·26	1·53	1·66	2·82	3·82	7·48	5·92	2·29	33·18	..
Ramnad—														
1 Theethandathanam	1·41	0·79	0·68	1·76	1·10	0·86	1·33	2·21	2·20	7·14	8·26	4·61	32·35	6·05
2 Vattanam	1·17	0·86	0·85	2·27	1·41	0·87	1·08	1·07	2·11	7·71	8·24	5·01	33·50	6·30
3 Tiruvandanai	1·21	0·53	0·31	1·47	1·17	1·14	1·39	2·47	3·12	6·85	7·18	3·35	30·19	5·67
4 Sivaganga	0·72	0·45	0·50	1·48	2·23	1·70	2·02	4·48	4·58	7·11	5·39	2·50	33·16	4·54
5 Manamadura	1·03	0·41	0·23	1·10	2·36	1·57	1·66	5·61	5·06	6·52	6·21	1·85	35·80	6·50
6 Tiruppattur	0·75	0·34	0·31	1·36	2·61	2·00	2·78	6·37	4·04	5·41	5·35	3·11	35·34	6·22
7 Tiruppuvanam	1·64	0·36	0·29	1·22	3·03	2·04	2·36	3·96	3·09	6·41	6·59	1·99	29·88	7·45
8 Paramakudi	1·04	0·47	0·37	2·35	2·08	0·74	1·73	2·76	3·41	6·12	6·66	2·81	30·54	5·68
9 Ramnad	1·08	0·71	0·83	1·92	1·11	0·44	0·89	1·75	2·00	7·38	9·43	4·97	32·51	7·42
10 Pamban	2·13	0·73	0·53	1·62	0·83	0·13	0·57	0·73	1·20	9·04	12·00	7·49	37·00	5·26
11 Kumudhi	1·03	0·37	0·50	1·74	2·09	0·46	1·56	1·58	2·50	6·97	6·13	2·06	28·19	5·50
12 Morekulam	1·08	0·53	0·71	1·88	1·68	0·45	1·17	1·76	2·36	6·76	6·03	3·10	27·49	5·70
13 Mudukulattur	1·24	0·85	0·75	1·88	1·11	0·35	0·41	0·66	1·05	6·17	9·68	5·48	30·43	5·50
14 Aruppukkottai	1·65	0·57	0·76	1·68	1·97	1·36	1·64	2·99	3·51	5·97	6·90	2·36	31·36	5·73
15 Sattur	0·70	0·54	0·94	1·97	2·46	0·54	0·93	1·65	2·36	7·00	4·85	2·14	26·16	5·00
16 Watrap	0·67	0·51	0·57	2·26	2·75	0·98	1·27	2·78	4·34	8·73	4·04	2·31	30·11	3·53
17 Srivilliputtur	1·28	0·41	0·80	2·02	2·43	0·76	0·92	2·03	2·73	7·28	6·01	2·71	29·38	6·15

Average monthly and annual rainfall of the Madras Presidency up to the year 1941—cont.

District and station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.	Highest rainfall.
Ramnad—cont.														
18 Virudunagar	1·01	1·12	1·22	1·96	2·36	0·62	0·71	1·10	1·87	7·18	6·00	2·69	27·84	5·42
19 Sivakasi	1·06	1·17	1·21	2·35	2·21	0·57	0·54	1·26	2·62	8·61	6·71	2·41	30·72	4·60
Average ..	**1·15**	**0·61**	**0·65**	**1·82**	**1·95**	**0·93**	**1·31**	**2·53**	**2·85**	**6·98**	**6·96**	**3·32**	**30·83**	..
Tinnevelly—														
1 Vilattikulam	0·87	0·60	0·89	1·63	1·22	0·33	0·42	1·59	2·19	6·97	5·97	2·38	25·06	3·77
2 Arasadi	1·45	0·78	1·13	1·41	0·75	0·21	0·18	0·26	0·53	6·46	6·55	2·98	22·69	6·05
3 Tuticorin	1·11	0·64	0·96	1·58	0·88	0·18	0·13	0·26	0·58	5·27	7·09	3·20	21·88	7·82
4 Ottappidaram	1·19	0·59	0·82	1·50	1·35	0·39	0·39	1·01	1·56	7·00	6·64	2·78	25·22	7·97
5 Kayattar	1·42	0·58	0·75	2·48	1·63	0·23	0·75	1·12	1·46	7·49	6·44	2·76	27·02	7·15
6 Koilpatti	1·30	0·51	0·51	2·56	2·45	0·70	0·76	1·45	2·31	7·15	7·13	2·75	29·58	3·55
7 Sankarankoil	1·12	0·97	1·52	2·63	1·76	0·63	0·45	0·52	0·95	6·52	6·19	3·12	26·38	3·04
8 Sivagiri	2·80	1·88	1·89	2·67	1·61	0·99	1·20	1·01	1·32	9·20	9·31	3·78	37·61	4·40
9 Kadayanallur	2·11	1·04	1·88	1·88	1·24	2·20	1·22	0·75	0·92	7·59	8·13	4·02	32·98	5·70
10 Tenkasi	2·15	1·48	2·32	3·00	2·13	4·28	3·05	1·33	0·93	6·68	8·89	4·52	40·76	8·30
11 Kadayam	3·75	1·15	1·81	1·90	1·82	1·85	1·74	0·98	0·84	7·58	10·12	6·84	40·38	4·81
12 Ambasamudram	2·48	1·46	1·89	1·98	1·67	1·37	0·82	0·52	0·52	5·83	9·92	6·28	34·74	5·15
13 Palamcottah	1·50	0·80	0·95	2·49	1·57	1·56	0·38	0·56	1·30	6·82	7·41	4·00	28·34	7·98
14 Nanguneri	1·50	1·00	1·71	1·74	1·42	1·05	0·40	0·61	1·13	5·85	7·57	4·69	28·67	6·01
15 Radhapuram	0·85	0·72	1·52	1·60	1·14	2·21	1·21	0·50	0·46	5·86	7·03	3·68	26·68	6·70
16 Sattankulam	1·18	0·80	0·54	0·86	0·92	0·43	0·37	0·64	0·04	6·98	7·69	4·02	25·37	4·20
17 Kulasekarapatnam	1·48	0·97	1·22	1·27	0·59	0·35	0·19	0·15	0·23	5·47	9·09	5·49	26·50	12·40
18 Kiranur	1·91	0·52	0·79	1·17	0·54	0·16	0·15	0·10	0·35	5·87	7·77	3·99	23·32	6·75
19 Srivaikuntam	1·22	0·70	1·14	1·39	1·39	0·33	0·32	0·55	1·07	6·08	7·18	3·79	25·16	5·26
20 Tinnevelly	1·88	0·38	0·64	2·38	1·61	0·50	0·36	0·39	1·85	7·27	8·16	5·07	30·49	9·88
21 Tiruchendur	3·70	0·06	0·93	0·84	0·49	0·13	0·19	0·16	0·22	6·42	11·37	6·07	31·58	6·15
Average ..	**1·75**	**0·89**	**1·23**	**1·86**	**1·34**	**0·91**	**0·70**	**0·68**	**1·02**	**6·66**	**7·89**	**4·10**	**29·07**	..
Travancore State—I. Kottayam Division—														
1 Chinnar	1·66	0·24	0·50	1·16	1·91	1·35	1·79	1·25	2·15	5·20	4·45	2·42	24·08	5·80
2 Marayur	2·87	0·02	0·84	2·35	2·96	3·84	4·94	2·93	5·08	4·20	10·30	2·76	43·09	8·33
3 Malayattur	0·91	0·53	1·96	5·98	11·51	31·72	30·84	21·88	11·91	13·98	9·30	2·42	142·94	7·02
4 Parur	0·29	0·42	1·21	3·36	9·67	31·06	26·70	13·67	9·32	12·11	6·05	1·01	114·87	8·80
5 Perumpavur	0·40	0·60	1·30	4·01	7·79	24·49	26·87	15·67	8·99	10·98	7·88	1·29	110·27	8·70
6 Alwaye	1·13	0·18	1·05	2·79	11·69	27·86	19·71	14·96	13·23	11·20	11·40	1·97	117·26	7·60
7 Munnar	1·07	0·42	1·17	5·46	11·10	39·26	31·84	24·10	13·57	8·61	8·74	1·01	146·25	5·82

8 Devikulam	0·82	0·81	1·75	4·71	6·97	20·44	25·62	15·22	10·81	11·99	7·29	1·45	107·88	6·19
9 Nerlamangalam (Excluded)	..	..	..	..	..	..	..	..	..	..	..	..	..	..
10 Muvattupuzha	0·38	0·68	1·60	5·24	8·70	29·16	28·82	17·74	9·84	14·80	8·59	1·79	127·54	7·55
11 Santanpara	1·89	1·08	1·99	5·02	4·70	11·23	9·45	5·26	5·33	12·53	9·10	3·18	70·85	2·00
12 Karikode	0·76	1·42	2·55	8·12	12·35	30·73	30·31	21·07	12·39	18·62	8·67	1·87	148·86	5·60
13 Vandanmettu (excluded)	..	..	..	..	..	..	..	..	..	..	..	..	..	..
14 Vaikom	0·76	0·76	1·74	2·95	8·76	25·61	22·82	12·35	8·60	11·31	6·83	1·64	104·16	6·65
15 Pala	1·10	1·66	4·70	10·33	13·41	29·93	28·55	17·72	11·61	18·20	11·40	3·54	152·15	6·02
16 Ettumanur	0·56	0·54	1·59	6·52	8·76	29·38	26·01	14·94	9·01	11·53	5·58	2·26	116·68	5·64
17 Kumizhi	1·51	0·87	1·17	2·53	4·46	14·12	12·72	5·39	3·78	8·18	7·57	3·11	65·41	2·02
18 Kottayam (Taluk Office)	0·63	0·72	2·27	5·38	9·02	27·13	23·43	14·00	9·88	14·96	7·72	2·72	117·86	6·14
19 Kottayam (Public Works Department Office).	0·70	0·64	2·24	5·67	9·77	29·56	25·08	14·82	10·80	14·84	6·99	3·21	124·32	6·20
20 Peermade (Taluk Office)	0·72	1·58	2·48	6·25	13·79	54·39	45·93	22·52	17·78	20·73	10·67	1·88	198·67	9·08
21 Peermade (Residency)	0·71	1·47	2·46	6·01	10·92	48·22	50·67	33·22	19·25	19·76	9·05	1·70	203·44	9·85
22 Kanjirapalli	1·57	2·21	5·79	12·11	14·58	31·13	27·82	18·90	15·03	21·84	13·26	3·54	167·78	8·60
23 Changanacherry	0·60	0·84	2·48	6·56	9·61	25·69	19·86	11·99	8·68	15·87	8·35	2·20	112·82	5·72
Average ..	**0·97**	**0·84**	**2·04**	**5·36**	**9·17**	**26·36**	**24·75**	**15·22**	**10·32**	**13·40**	**8·91**	**2·25**	**119·27**	..
Travancore State—II. Quilon Division—														
1 Areputty	1·59	0·65	1·53	4·93	11·57	29·75	26·33	14·04	10·76	13·58	7·98	2·63	125·34	9·05
2 Cherthala	0·90	0·83	1·72	3·75	9·74	25·71	22·06	11·42	7·69	12·37	6·87	1·97	105·03	6·30
3 Alleppey (Taluk Office)	1·14	1·50	2·17	5·58	10·44	26·65	21·26	11·05	7·87	15·47	9·39	2·43	114·95	8·85
4 Alleppey (Public Works Department Office).	2·07	1·35	1·73	4·71	13·32	27·09	17·34	13·53	9·89	12·29	11·11	1·63	116·06	7·50
5 Ambalapuzha	0·82	0·97	2·58	5·48	9·56	24·00	18·61	9·37	8·05	14·56	7·90	2·25	104·15	8·20
6 Tiruvalla	0·60	0·96	1·58	4·90	9·11	24·60	21·32	10·92	8·20	12·60	7·08	1·86	103·73	10·10
7 Chengannur	0·95	1·00	2·89	6·64	9·33	24·06	20·33	11·98	9·61	13·50	8·93	3·00	112·22	9·02
8 Haripad	0·91	0·67	1·35	3·77	7·85	22·26	17·37	8·71	7·02	13·05	7·26	2·04	92·26	8·05
9 Puttannomthitta	1·63	1·22	3·56	7·73	11·45	21·97	20·13	13·99	11·34	16·49	12·80	2·63	124·94	7·00
10 Mavelikara	0·83	0·81	1·65	5·12	8·96	26·65	20·85	11·62	8·63	15·01	8·60	2·47	111·20	8·50
11 Konni	1·08	1·73	4·69	8·93	12·30	23·30	21·08	14·97	11·67	18·37	13·02	2·29	133·43	7·05
12 Kayankulam	0·89	0·49	1·73	4·13	9·41	21·81	15·60	8·99	8·30	12·23	7·95	1·98	93·51	10·47
13 Adur	0·58	1·36	2·68	7·39	8·96	22·19	17·63	11·19	7·95	14·85	8·09	2·17	105·04	8·80
14 Karunagapalli	0·62	0·84	1·52	3·96	8·54	21·51	14·57	7·82	6·95	12·00	6·39	1·65	86·87	10·00
15 Punalur	0·71	1·80	3·16	8·63	9·65	23·20	19·37	11·63	9·74	17·61	9·99	2·06	117·55	7·20
16 Kottarakara	0·58	1·21	2·79	7·02	8·36	22·32	16·13	9·99	7·96	15·64	8·58	1·98	102·56	7·90
17 Ayaikkudi	3·80	0·69	1·49	2·69	1·54	2·04	0·74	0·25	0·58	4·50	10·12	2·43	30·87	7·00
18 Aryankavu	1·38	1·05	2·68	2·65	5·63	19·98	15·87	10·25	8·17	15·05	11·39	3·24	97·34	6·05
19 Shenkotta (Public Works Department Office.)	5·88	1·15	2·53	2·76	3·87	9·29	3·83	2·03	2·51	6·74	10·53	3·02	54·14	5·00
20 Shenkotta (Taluk Office)	2·29	1·51	2·28	3·62	2·38	8·58	6·31	2·58	1·95	7·74	8·38	3·97	51·59	4·98
21 Quilon (Public Works Department Office).	0·98	0·44	1·55	4·89	9·37	20·83	14·10	7·50	6·98	10·90	7·81	1·63	86·98	7·92
22 Quilon (Taluk Office)	0·63	0·89	1·61	4·45	7·62	19·10	13·09	7·90	6·62	13·24	7·12	1·40	83·58	8·10
23 Paravur	0·39	0·72	1·63	4·46	8·84	20·13	12·15	7·25	6·34	11·98	6·48	1·43	81·80	6·50
Average ..	**1·37**	**1·06**	**2·28**	**5·21**	**8·40**	**20·50**	**15·60**	**9·22**	**7·44**	**13·04**	**9·00**	**2·26**	**95·43**	..

Average monthly and annual rainfall of the Madras Presidency up to the year **1941—cont.**

District and station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.	Highest rainfall.
Travancore State—III. Trivandrum Division—														
1 Attingal	0·65	0·82	1·08	4·15	6·36	17·09	10·57	4·93	4·55	11·67	5·89	1·69	69·45	6·75
2 Nedumangad	1·05	1·22	2·29	7·01	7·39	17·80	10·55	5·87	5·95	14·95	9·82	2·93	86·85	9·66
3 Trivandrum	0·74	0·61	1·62	4·47	8·45	13·39	7·41	4·07	4·14	10·58	6·59	2·44	64·51	8·74
4 Neyyattinkarai	0·96	0·68	1·26	3·72	5·81	12·37	6·67	2·82	3·80	10·42	8·64	2·66	59·82	5·30
5 Parassala	0·69	0·38	1·38	3·57	6·39	11·61	5·26	2·40	4·62	9·76	8·17	2·26	56·49	6·24
6 Pechippara	2·68	0·71	3·91	5·29	7·42	15·18	6·42	4·05	11·47	12·45	10·74	2·61	82·93	7·20
7 P.P. Channel	1·98	0·50	2·14	3·49	4·40	10·94	3·76	1·64	3·01	8·94	10·69	1·69	53·18	3·20
8 Kaliyal	3·38	0·16	3·10	6·84	7·56	15·70	5·63	4·33	8·49	16·02	12·23	3·67	87·11	6·40
9 Kulaskharam	2·67	0·96	4·14	5·70	8·02	14·73	5·03	4·54	8·61	14·19	12·29	3·93	84·82	5·45
10 Puttan Dam	2·53	0·62	2·62	5·02	6·64	13·14	4·65	4·19	7·13	14·23	9·58	2·59	72·94	6·10
11 Chorlakod	1·69	0·91	2·57	3·88	6·00	14·06	5·29	4·23	8·48	12·45	9·35	1·92	91·78	5·50
12 Tiruvattar	1·01	0·78	2·26	3·79	5·30	11·70	5·53	2·96	4·50	12·29	9·47	3·34	62·83	4·77
13 Thadikkarankonam	1·51	0·18	3·37	3·93	5·76	13·75	5·81	3·36	6·85	14·32	10·41	1·27	70·52	4·75
14 Seetappal	1·89	0·07	2·32	2·23	4·39	10·36	3·55	1·67	2·96	10·87	8·64	3·40	21·35	3·30
15 Kuzhitura	1·62	0·68	1·05	3·19	3·98	9·60	4·62	1·89	2·86	9·03	7·28	2·42	47·22	5·40
16 Mekod	1·72	0·30	2·39	3·79	6·22	13·77	4·31	3·05	6·53	13·08	9·45	2·01	66·62	9·45
17 Mulakumud	1·85	0·58	1·80	3·78	6·00	13·46	4·96	2·62	4·39	11·41	12·62	2·37	66·74	4·60
18 Bhuthappandi	0·98	0·64	1·93	3·61	2·80	9·17	4·66	2·11	1·97	10·02	7·47	2·74	48·10	3·17
19 Armboli	1·49	0·63	1·49	2·69	1·71	5·60	4·55	0·94	1·22	8·19	7·40	2·86	36·77	3·21
20 Takkala Kalukulam	1·94	0·91	2·77	3·70	6·22	12·48	4·16	1·84	4·68	10·49	11·90	2·92	64·01	4·70
21 Eraniyal	0·71	0·48	0·92	2·90	2·96	7·92	3·59	1·07	2·13	7·70	6·46	1·93	38·73	4·45
22 Kolachal (Salt factory)	0·89	0·28	0·56	1·81	4·04	9·35	5·23	1·66	3·09	8·20	7·29	2·27	44·67	5·58
23 Kolachal (Police Office)	0·76	0·16	0·40	1·89	4·16	9·52	4·25	1·39	2·51	7·03	7·10	2·31	41·45	5·07
24 Nagercoil (Public Works Department)	1·07	0·42	0·97	3·22	2·29	7·38	3·39	1·55	1·66	8·08	7·09	2·70	39·83	4·50
25 Nagercoil (Taluk Office)	0·92	0·48	0·90	2·81	1·80	6·06	2·88	1·20	1·15	7·95	6·83	2·66	35·64	5·52
26 Rajakkamangalam	1·03	0·26	1·02	2·53	3·01	8·38	3·44	1·49	1·83	7·55	7·27	2·71	40·52	5·52
27 Tamarakulam old salt factory. ..	0·79	0·35	0·90	2·35	1·64	5·53	2·40	1·06	1·08	7·21	6·81	2·85	32·97	5·47
28 Tamarakulam new salt factory ..	0·77	0·13	0·67	1·02	2·25	4·55	2·66	0·73	1·37	6·10	6·85	2·74	29·84	5·67
29 Kottaram	1·85	0·03	1·92	1·96	2·50	5·33	2·22	0·80	1·44	4·45	6·87	1·62	31·00	4·35
Average ..	**1·43**	**0·49**	**1·84**	**3·54**	**4·62**	**10·98**	**4·78**	**2·54**	**4·25**	**10·08**	**8·63**	**2·52**	**58·00**	..
Cochin State—														
1 Ernakulam	0·45	0·87	1·62	4·11	10·33	28·14	23·06	13·61	9·38	13·55	5·08	1·53	111·73	4·45
2 Cranganore	0·26	0·47	1·10	2·32	12·52	30·02	26·70	14·64	9·86	12·81	8·03	0·93	119·66	11·24
3 Irinjalakuda	0·68	0·17	1·00	2·73	11·33	30·60	27·55	15·30	9·67	12·68	8·66	1·10	121·47	12·42
4 Trichur	0·24	0·22	0·79	3·42	8·89	34·32	30·11	16·87	9·90	14·07	5·81	0·53	125·17	7·83
5 Wadakkancherry	0·39	0·17	0·60	2·24	7·85	30·34	29·77	15·42	7·41	10·84	6·15	0·83	112·01	6·68
6 Chittur	0·29	0·45	0·83	2·53	3·56	14·46	18·31	9·22	4·35	7·32	4·49	0·97	66·78	10·25
Average ..	**0·39**	**0·88**	**0·99**	**2·89**	**9·08**	**27·98**	**25·91**	**14·17**	**8·42**	**11·87**	**6·37**	**0·98**	**109·47**	..

Malabar—														
1 Alattur	0·43	0·08	1·08	2·25	5·36	18·86	22·45	12·59	5·80	8·44	6·75	1·00	85·09	4·66
2 Palghat	0·26	0·36	0·90	2·71	4·96	17·04	21·21	11·76	6·08	8·28	3·95	0·94	78·45	3·76
3 Parli	0·54	0·23	0·96	2·46	6·19	21·20	26·88	13·55	6·89	11·83	5·55	1·62	97·90	4·00
4 Ottapalam	0·48	0·28	0·91	2·37	6·40	23·04	25·59	13·73	6·62	10·47	6·19	1·17	98·25	6·50
5 Cherpalacherry	0·29	0·24	0·86	3·01	7·28	25·39	27·22	13·27	7·14	12·08	6·47	1·25	104·50	4·30
6 Mannarghat	0·22	0·32	1·14	3·67	8·01	26·07	30·37	14·50	10·22	14·44	7·87	1·35	118·18	3·14
7 Perintalamanna	0·17	0·26	0·91	3·98	7·05	26·62	26·96	13·50	7·31	12·79	5·80	1·89	106·24	5·81
8 Manjeri	0·18	0·19	0·60	3·11	6·69	29·55	29·23	14·68	7·10	11·97	6·04	0·93	110·27	6·27
9 Nilambur	0·15	0·18	0·50	2·63	5·60	28·12	38·82	15·59	7·89	9·99	4·73	0·92	110·12	4·25
10 Vayittiri	0·29	0·49	1·07	4·25	6·91	45·68	54·41	27·36	11·25	10·74	4·82	1·09	168·36	9·56
11 Manantoddy	0·16	0·27	0·92	3·40	5·17	24·84	36·35	19·29	7·17	6·66	2·64	0·52	107·89	5·86
12 Irikkur	0·17	0·21	0·32	1·58	8·74	39·42	45·78	25·03	9·88	11·90	5·97	1·13	150·13	6·75
13 Payyanur	0·15	0·18	0·17	0·74	7·82	39·86	39·15	20·25	8·90	8·51	3·83	0·85	130·41	7·93
14 Taliparamba	0·13	0·11	0·09	1·81	6·85	38·74	39·10	20·81	8·67	8·12	4·31	0·71	129·45	6·74
15 Cannanore	0·25	0·26	0·18	2·15	7·78	38·22	35·17	18·83	8·63	7·95	3·67	0·61	123·60	5·90
16 Tellicherry	0·30	0·20	0·27	2·76	9·21	39·50	35·64	18·94	8·93	8·44	3·81	0·82	128·82	8·72
17 Badagara	0·38	0·32	0·38	2·99	8·67	38·65	35·36	18·18	8·38	9·06	4·73	0·59	127·69	9·40
18 Kuttiyadi	0·61	0·34	0·55	3·54	11·73	41·47	48·41	26·41	12·05	14·97	10·26	2·58	72·92	9·71
19 Quilandi	0·23	0·15	0·82	2·90	8·35	37·50	34·70	18·17	8·25	9·33	4·70	0·96	125·56	8·92
20 Calicut	0·40	0·16	0·47	3·28	8·53	34·08	30·24	15·58	7·73	10·22	5·38	1·09	117·16	10·57
21 Tirurangadi	0·16	0·27	0·36	3·09	9·20	32·28	27·79	13·75	7·43	10·35	4·96	1·27	110·84	11·62
22 Ponnani	0·23	0·43	0·93	4·23	0·79	28·88	24·43	12·68	7·10	10·89	5·68	0·99	106·26	5·99
23 Chowghat	0·31	0·24	0·65	3·86	10·05	29·26	26·10	13·41	7·97	11·55	6·46	1·10	110·96	11·42
24 Tripriar	0·50	0·15	0·81	2·37	11·00	28·91	27·19	13·18	8·79	11·95	7·08	1·68	113·11	10·20
25 Cochin	0·69	0·79	2·00	4·71	11·67	28·49	22·84	12·80	8·98	13·22	6·54	1·74	114·56	9·07
Average	**0·31**	**0·27**	**0·69**	**2·99**	**7·96**	**31·27**	**32·25**	**16·72**	**8·01**	**10·17**	**5·53**	**1·11**	**117·67**	..
South Kanara—														
1 Hosdrug	0·09	0·13	0·09	1·85	6·46	39·93	39·01	21·67	9·19	6·82	3·08	0·47	128·79	11.39
2 Kasaragod	0·18	0·09	0·10	1·58	7·09	38·43	37·89	22·40	10·03	7·12	2·97	0·60	128·42	7·85
3 Puttur	0·26	0·11	0·32	1·91	5·86	36·37	45·37	27·40	12·19	10·69	4·10	0·65	145·23	9·90
4 Beltangadi	0·09	0·07	0·25	2·12	5·14	39·78	57·86	35·48	14·81	12·42	4·79	0·76	178·57	11·55
5 Bantwal	0·08	0·05	0·04	1·37	4·48	39·33	45·56	26·68	11·21	8·79	3·33	0·79	141·71	7·08
6 Mangalore	0·06	0·06	0·[illegible]8	1·28	6·20	36·78	37·11	22·54	10·42	7·53	2·12	0·50	128·68	8·70
7 Mulki	0·09	0·06	0·02	1·27	5·85	38·96	40·70	24·65	11·54	6·76	3·02	0·43	133·25	11·35
8 Karkal	0·18	0·02	0·15	1·98	5·90	45·84	59·82	37·08	15·87	12·98	4·63	1·03	185·48	11·89
9 Udipi	0·13	0·06	0·03	0·95	5·44	38·52	44·63	27·10	13·18	7·54	2·34	0·41	140·33	10·73
10 Coonoor	0·16	0·05	0·07	0·74	5·43	39·76	44·24	26·70	13·77	7·13	2·06	0·37	140·48	7·92
11 Baindur	0·10	0·03	0·01	0·62	4·69	41·53	51·96	30·22	14·11	7·15	2·83	0·40	153·65	8·03
Average	**0·14**	..	**0·10**	**1·42**	**5·68**	**39·57**	**45·83**	**27·45**	**12·39**	**8·63**	**3·39**	**0·58**	**145·08**	..
Salem—														
1 Thalli	0·26	0·12	0·45	1·41	4·79	2·79	3·68	4·77	7·20	5·97	3·06	0·53	35·03	3·15
2 Denkanikota	0·31	0·19	0·42	1·62	4·71	2·32	2·60	3·55	5·23	6·25	4·01	0·92	32·13	4·75
3 Hosur	0.27	0·32	0·48	1·63	4·41	2·15	2·53	4·11	5·68	5·97	3·42	0·91	31·88	5·03
4 Rayakota	0·67	0·35	0·52	1·40	4·78	2·03	2·88	3·80	7·10	7·08	4·79	1·49	36·89	4·94
5 Krishnagiri	0 27	0·27	0·47	0·97	4·20	2·30	3·04	4·06	6·70	5·45	3·55	1·14	32·42	4·54

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Average monthly and annual rainfall of the Madras Presidency up to the year 1941—*cont.*

District and station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.	Highest rainfall.
Salem—*cont.*														
6 Uttangarai	0·39	0·24	0·40	0·83	3·48	1·95	2·82	4·81	6·67	5·98	4·46	1·31	33·34	3·88
7 Harur	0·81	0·36	0·39	0·81	3·23	1·65	2·64	4·42	6·17	5·50	4·04	2·31	33·23	3·03
8 Dharmapuri	0·36	0·24	0·46	1·05	4·16	2·14	2·42	4·43	6·08	5·98	3·84	1·27	32·43	3·09
9 Palacode	0·57	0·18	0·40	1·36	4·32	2·19	3·31	4·51	5·92	6·77	3·45	0·74	32·72	5·14
10 Pennagaram	0·27	0·31	0·64	1·38	4·74	2·40	2·55	4·02	5·57	6·34	3·76	0·97	32·95	4·15
11 Omalur	0·26	0·32	0·44	1·47	4·16	2·40	3·48	4·98	5·83	5·83	3·87	0·92	33·55	4·22
12 Sa em	0·31	0·27	0·48	1·79	4·72	3·02	3·82	6·84	6·59	6·74	3·74	0·98	39·30	6·94
13 Rasipur	0·19	0·29	[illegible]	1·33	4·05	2·47	3·30	5·32	5·45	5·82	3·58	0·71	32·84	4·22
14 Sankari	0·22	0·34	0·54	1·39	4·08	1·90	3·32	4·37	5·30	5·79	3·38	0·90	30·62	4·30
15 Tiruchengode	0·26	0·19	0·45	1·30	3·51	1·72	1·97	3·84	4·54	5·93	2·55	0·97	28·23	3·65
16 Thammampatti	1·32	0·63	0·31	1·51	4·21	1·48	2·42	3·66	4·84	6·53	6·17	1·95	35·03	5·10
17 Attur	0·55	0·35	0·78	1·38	3·81	1·71	2·66	4·52	6·54	7·40	5·50	1·39	36·59	5·00
18 Valappadi	0·97	0·29	0·30	0·89	3·84	1·87	2·99	4·79	5·94	5·20	4·45	1·01	32·64	4·15
19 Namakkal	0·23	0·14	0·44	1·42	4·15	1·43	2·12	4·08	4·53	5·52	3·66	0·92	28·64	4·03
20 Paramathi	0·30	0·26	0·47	1·41	3·86	1·14	1·11	2·87	3·43	5·51	3·48	1·12	24·96	3·28
21 Sendamangalam	0·39	0·23	0·18	1·36	4·31	1·61	2·66	4·36	6·13	5·76	3·38	0·75	31·12	7·00
22 Yercaud	0·78	0·59	0·80	2·32	6·54	5·30	7·13	10·47	10·38	9·60	6·72	3·07	66·70	..
Average ..	**0·45**	**0·29**	**0·46**	**1·37**	**4·48**	**2·29**	**2·93**	**4·60**	**5·99**	**6·23**	**4·09**	**1·10**	**34·08**	..
Coimbatore—														
1 Kollegal	0·14	0·17	0·68	2·06	5·19	2·64	2·46	4·31	6·10	7·10	2·69	0·58	34·12	3·70
2 Talavadi	0·34	0·14	0·61	2·55	5·36	1·87	2·03	2·89	5·33	6·39	3·33	0·88	31·22	4·35
3 Satyamangalam	0·48	0·40	0·58	1·58	3·40	1·43	1·33	2·30	3·84	6·97	4·41	0·83	27·55	4·11
4 Gobichettipalaiyam	0·45	0·33	0·68	1·72	3·61	1·53	1·50	2·87	4·89	7·14	4·00	0·75	29·47	5·04
5 Bhavani	0·26	0·31	0·72	1·78	3·49	1·74	2·05	3·45	4·52	6·47	3·88	1·17	29·84	3·50
6 Erode	0·22	0·15	0·61	1·72	3·75	1·53	1·81	3·54	4·43	6·33	3·80	1·19	29·08	5·40
7 Perundurai	0·82	0·27	0·53	1·38	3·38	1·27	1·39	2·88	4·34	5·58	3·44	1·16	25·94	4·10
8 Kodumudi	0·49	0·22	0·40	1·19	3·75	0·86	1·35	2·31	3·93	4·89	4·03	0·91	24·33	3·37
9 Udamalpet	0·32	0·38	0·54	1·94	2·62	1·13	0·72	0·61	1·16	6·03	5·45	1·82	22·72	7·84
10 Dharapuram	0·39	0·31	0·50	1·62	3·13	0·80	0·47	0·78	1·84	5·65	4·00	1·67	21·25	7·25
11 Kangayam	0·48	0·27	0·61	1·68	3·59	1·11	0·72	1·29	1·96	5·88	5·71	1·40	23·70	4·87
12 Avanashi	0·57	0·32	0·50	1·42	3·56	1·33	1·22	2·29	3·92	6·96	3·70	1·15	26·94	4·47
13 Sulur	0·61	0·18	0·39	1·12	2·62	0·78	0·68	0·99	1·92	6·78	3·74	1·26	21·07	7·78
14 Palladam	0·36	0·30	0·40	1·43	2·94	0·83	0·45	0·97	2·18	6·36	3·89	1·20	21·31	3·64
15 Coimbatore	0·59	0·32	0·48	1·44	2·36	1·66	1·46	1·13	1·51	6·41	3·75	1·18	22·29	3·97
16 Perianayakanpalaiyam	1·22	0·52	0·61	1·85	3·37	1·10	1·11	1·62	2·83	6·69	5·34	2·08	28·34	2·95
17 Mettupalaiyam	1·11	0·62	1·12	2·71	3·01	1·21	1·16	1·69	2·58	8·59	6·01	1·97	31·78	7·97
18 Pollachi	0·24	0·32	0·44	2·40	3·18	4·02	5·35	2·39	1·64	5·50	4·49	1·24	31·21	5·77
19 Annur	0·77	0·22	0·72	1·25	3·16	1·59	1·10	2·40	2·60	5·69	4·36	0·97	24·74	5·10
20 Tiruppur	0·71	0·15	0·32	0·77	3·22	1·09	1·28	1·60	3·01	6·44	5·04	0·90	24·62	4·68
Average ..	**0·50**	**0·30**	**0·57**	**1·68**	**3·43**	**1·48**	**1·48**	**2·09**	**3·28**	**6·39**	**4·26**	**1·21**	**26·58**	..

The Nilgiris—														
1 Devala ..	0·32	0·21	0·66	3·00	6·77	31·67	45·21	32·20	18·80	12·10	4·57	1·45	156·85	9·30
2 Gudalur	0·30	0·28	0·74	2·71	5·14	16·83	27·82	16·66	8·13	7·10	2·97	0·74	89·42	12·06
3 Naduvattam	0·55	0·32	0·68	2·99	5·49	18·49	30·45	18·15	8·87	8·40	3·89	1·08	99·45	8·57
4 Ootacamund	0·93	0·57	1·12	3·17	6·17	6·70	7·66	5·19	5·69	8·12	4·96	1·77	52·14	2·89
5 Kundah bridge	1·61	..	..	..	..	5·08	..	..	4·52	10·83	8·42	3·08	55·25	3·90
6 Ketty ..	1·31	1·01	1·45	3·25	5·51	4·61	5·09	4·78	6·52	9·27	6·00	2·49	51·29	3·90
7 Coonoor	..	..	..	..	..	..	..	..	..	..	..	..	..	3·17
8 Kotagiri	2·38	2·32	1·94	4·12	6·00	4·08	4·74	4·33	6·63	14·35	10·16	4·30	65·35	5·73
9 Kodanad	1·60	1·32	1·08	2·93	6·52	3·69	4·50	4·07	7·04	11·92	8·73	3·96	57·36	5·30
10 Hullthi ..	1·41	0·89	0·94	2·71	5·83	3·54	3·52	2·57	5·82	7·27	8·33	0·86	43·69	6·40
Average ..	**1·10**	**0·88**	**1·07**	**3·11**	**5·27**	**10·53**	**14·33**	**9·77**	**8·00**	**9·83**	**6·44**	**2·27**	**74·54**	..
Coorg—														
1 Mercara ..	0·15	0·19	0·61	2·63	5·65	26·36	40·93	25·45	10·82	8·72	3·21	0·74	125·46	9·30
2 Virajpet	0·12	0·23	0·48	2·72	5·98	26·23	32·41	15·23	7·78	8·35	3·09	0·56	103·18	5·44
3 Fraserpet	0·11	0·25	0·39	2·39	5·25	7·21	8·68	4·53	3·31	6·43	3·03	0·70	42·28	3·52
4 Somwarpet	0·15	0·14	0·33	2·33	4·30	14·74	28·19	15·39	6·00	7·05	3·63	0·77	83·02	4·70
5 Ammatti	0·26	0·21	0·46	2·33	6·57	17·80	23·73	12·38	6·51	8·64	4·24	0·55	83·68	4·30
6 Napoklu	0·36	0·30	1·47	5·35	6·66	26·21	39·22	19·10	7·52	9·55	3·63	0·69	120·06	5·79
7 Sanivarsante	0·09	0·12	0·31	1·94	4·22	12·20	22·24	12·85	5·23	6·63	3·00	0·67	69·59	3·01
8 Ponnampet	0·25	0·15	0·34	2·33	6·10	23·01	31·35	14·08	7·75	8·11	3·53	0·24	97·24	5·50
9 Bhagamandla	0·30	0·20	0·67	3·78	11·39	58·66	82·34	45·75	13·84	15·36	6·53	0·69	244·51	11·87
10 Sunticoppa	0·13	0·18	0·30	2·22	5·50	13·62	19·06	10·93	5·45	7·17	3·76	0·35	68·67	6·26
Average ..	**0·19**	**0·20**	**0·54**	**2·88**	**6·17**	**22·73**	**32·94**	**17·23**	**7·73**	**8·58**	**3·79**	**0·58**	**103·56**	..
Cuddapah—														
1 Pulivendla	0·11	0·17	0·23	0·59	1·62	1·94	2·19	3·67	5·46	3·85	2·50	0·40	21·98	4·43
2 Jammalamadugu	0·12	0·13	0·17	0·39	1·42	2·02	2·70	4·08	5·29	3·86	1·92	0·34	22·44	4·00
3 Proddatur	0·18	0·13	0·12	0·53	1·25	2·58	3·06	4·83	5·75	4·06	2·29	0·39	25·17	3·48
4 Kamalapuram	0·32	0·17	0·13	0·55	0·90	2·66	3·10	4·99	5·70	3·79	2·70	0·48	25·43	5·46
5 Badvel ..	0·40	0·17	0·13	0·41	1·32	1·89	3·29	3·97	4·91	5·44	4·74	0·93	27·60	3·77
6 Sidhout ..	0·56	0·11	0·19	0·55	1·70	2·55	4·19	5·57	6·12	5·99	4·43	1·20	33·16	2·68
7 Chitvel ..	1·34	0·13	0·30	0·43	1·31	1·66	3·73	4·05	5·21	7·03	6·88	2·56	34·63	5·25
8 Rajampet	0·64	0·16	0·37	0·45	1·98	2·22	3·50	3·79	4·88	7·62	6·43	2·08	34·20	5·43
9 Rayachoti	0·36	0·10	0·29	0·59	1·68	2·08	2·53	3·68	5·42	4·49	3·62	0·86	25·71	4·25
10 Cuddapah	0·43	0·14	0·21	0·45	1·57	2·93	3·92	5·81	6·27	5·01	3·56	0·90	31·23	4·40
Average ..	**0·45**	**0·13**	**0·21**	**0·48**	**1·42**	**2·25**	**1·14**	**0·60**	**5·50**	**5·11**	**3·90**	**1·11**	**22·20**	..
Anantapur—														
1 Madakasira	0·12	0·09	0·23	0·80	3·07	2·28	2·20	2·58	4·87	5·08	1·91	0·28	23·51	4·35
2 Hindupur	0·08	0·13	0·17	0·67	2·68	2·27	2·44	3·63	5·15	4·38	1·97	0·29	23·26	4·18
3 Penukonda	0·15	0·14	0·16	0·85	2·42	2·24	2·21	2·96	5·84	4·53	2·22	0·37	24·09	3·90
4 Bukkapatnam	0·10	0·20	0·17	0·68	1·71	2·08	2·66	4·68	6·72	3·97	2·52	0·33	25·75	3·56
5 Dharmavaram	0·08	0·17	0·13	0·47	1·60	2·13	1·97	3·00	5·50	3·84	2·03	0·29	21·21	4·56
6 Kalyandrug	0·08	0·18	0·18	0·79	1·88	1·77	1·60	2·82	5·54	3·42	1·85	0·19	20·30	3·10
7 Anantapur	0·35	0·34	0·18	0·47	2·12	2·01	3·38	2·15	7·28	3·71	2·78	0·27	25·04	5·72
8 Uravakonda	0·11	0·17	0·20	0·76	1·86	2·02	2·17	3·09	6·08	3·65	1·65	0·13	21·89	3·05
9 Gooty	0·11	0·07	0·09	0·51	1·79	2·41	2·98	3·64	5·92	3·98	1·51	0·18	23·19	3·08

Average monthly and annual rainfall of the Madras Presidency up to the year **1941—*cont.***

District and station.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.	Highest rainfall.
Anantapur—*cont.*														
10 Yadiki	0·14	0·08	0·14	0·47	1·56	2·43	3·00	3·52	5·53	3·71	1·46	0·23	22·27	2·85
11 Tadpatri	0·11	0·11	0·15	0·46	1·42	2·26	3·69	4·10	5·77	4·11	1·65	0·28	23·11	3·96
12 Kadiri	0·19	0·12	0·33	0·62	2·17	2·05	2·67	3·94	5·77	4·88	2·41	0·44	25·59	3·07
13 Tanakal	0·41	0·23	0·35	0·77	1·52	1·18	2·69	1·72	5·48	2·16	3·47	0·11	20·09	3·75
Average ..	**0·16**	**0·13**	**0·19**	**0·64**	**1·98**	**2·08**	**2·40**	**3·17**	**5·83**	**3·96**	**2·11**	**0·26**	**23·02**	..
Bellary—														
1 Yemmiganur	0·08	0·23	0·42	0·64	1·12	2·49	3·66	4·06	5·60	3·32	1·30	0·22	23·10	3·25
2 Adoni	0·07	0·13	0·25	0·67	1·44	3·32	3·86	4·98	6·78	3·63	1·06	0·16	26·35	3·40
3 Alur	0·04	0·17	0·30	0·68	1·62	2·44	2·84	3·87	5·67	4·20	1·24	0·12	23·19	3·50
4 Siruguppa	0·08	0·15	0·27	0·72	1·56	2·75	2·87	4·22	6·28	4·05	1·27	0·11	24·33	4·25
5 Bellary	0·11	0·16	0·20	0·76	1·96	1·87	1·85	2·32	5·08	3·90	2·19	0·11	20·31	3·90
6 Rayadrug	0·10	0·16	0·13	0·61	2·10	2·04	1·52	2·28	4·79	3·84	1·71	0·22	19·50	3·77
7 Kampli	0·04	0·09	0·15	0·67	1·79	2·21	1·83	2·98	6·00	3·80	1·83	0·11	21·50	5·35
8 Hospet	0·03	0·08	0·12	0·71	2·29	3·09	3·14	4·40	6·40	4·07	1·63	0·36	26·32	4·67
9 Hadagalli	0·12	0·06	0·23	0·90	2·30	2·42	2·63	2·95	4·98	3·67	1·49	0·28	22·02	5·63
10 Harpanahalli	0·02	0·05	0·20	0·82	2·71	2·83	3·25	3·22	4·82	3·99	1·61	0·38	23·90	3·83
11 Kudligi	0·03	0·09	0·10	0·79	2·35	2·79	2·87	3·83	6·07	4·25	1·25	0·16	24·58	4·87
Average ..	**0·06**	**0·12**	**0·22**	**0·72**	**1·93**	**2·59**	**2·74**	**3·54**	**5·67**	**3·89**	**1·48**	**0·20**	**23·16**	..
Kurnool—														
1 Markapur	0·20	0·21	0·40	0·51	1·27	1·84	2·88	3·91	4·08	5·72	3·53	0·81	24·36	4·34
2 Cumbum	0·40	0·14	0·40	0·72	1·30	1·93	4·53	3·07	3·89	5·63	3·41	0·77	26·19	4·50
3 Giddalore	0·24	0·22	0·24	0·88	1·10	2·40	4·64	4·89	4·41	3·74	2·53	0·43	25·72	3·78
4 Allagadda	0·15	0·22	0·10	0·86	1·13	2·38	4·77	5·39	7·42	3·18	1·55	0·18	27·33	3·78
5 Nandyal	0·09	0·08	0·16	0·47	1·42	3·90	5·27	6·59	6·13	4·38	1·04	0·19	31·72	4·60
6 Vorvakal	0·28	0·10	0·12	0·65	0·96	2·75	3·51	4·09	5·95	3·35	1·12	0·16	23·04	3·00
7 Owk	0·25	0·22	0·15	0·33	1·16	1·64	2·22	3·08	5·19	3·91	1·49	0·20	19·94	2·00
8 Koilkuntla	0·11	0·09	0·13	0·50	1·25	2·72	3·47	4·63	6·08	3·78	1·33	0·22	24·31	2·91
9 Atmakur	0·13	0·11	0·20	0·74	1·10	2·71	6·66	6·38	6·40	3·79	1·11	0·24	30·57	5·85
10 Nandikotkur	0·13	0·09	0·19	0·55	1·42	3·23	5·10	5·59	6·29	3·37	0·91	0·13	27·00	5·35
11 Kurnool	0·18	0·16	0·26	0·56	1·06	2·93	4·80	5·04	6·17	3·47	1·14	0·24	26·01	3·66
12 Dhone	0·29	0·21	0·22	0·77	1·33	1·75	4·44	3·21	6·98	3·22	1·46	0·40	24·28	3·90
13 Peapalli..	0·10	0·10	0·16	0·78	1·40	2·54	3·77	4·05	6·04	4·12	1·32	0·20	24·58	3·06
14 Pattikonda	0·08	0·11	0·18	0·58	1·59	2·86	3·20	3·90	6·11	4·04	1·21	0·13	23·99	3·57
15 Gudur	0·24	0·23	0·35	0·38	1·76	1·75	4·16	4·24	6·86	2·67	1·20	0·11	23·95	3·60
Average ..	**0·13**	**0·15**	**0·23**	**0·81**	**1·32**	**2·54**	**4·23**	**4·51**	**6·00**	**3·92**	**1·85**	**0·30**	**25·69**	..

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GLOSSARY OF BOTANICAL NAMES

Alchi	*Acanthus ibicifolius.*
Aloe	*Agave americana*, Linn.
Anjan	*Hardwickia binnata.*
Babul	*Acacia arabica*, Willd.
Bajra or Bajri	See cumbu.
Bamboo	*Bambusa arundinacea.*
Bengal gram	*Cicer arictinum*, Linn.
Blue grass	*Digitaria longiflora*, Pers.
Cashewnut	*Anacardium occidentale*, Linn.
Caster	*Ricinus communis*, Linn.
Casuarina	*Casuarina equisetifolia*, Forest.
Chillies	*Capsicum* spp.
Cholam	*Sorghum vulgare*, Pers.
Clover	*Trifolium* spp.
Coconut	*Cocos nucifera*, Linn.
Corn	*Zea mays*, Linn.
Cotton	*Gossypium* spp.
Cumbu or kambu	*Pennisetum typhoides*, Satpf & Hubbard.
Darba grass	*Imperata cylindrica*, var. *koenigii.*
Dhall	See redgram.
Groundnut	*Arachis hypogaea*, Linn.
Guinea grass	*Panicum maximum*, Jacq.
Irukkai or Jilledu	*Calotropis gigantea*, R.Br.
Jowar	See cholam.
Kalimanda	*Plumeria acutifolia*, Poir.
Kambu	See cumbu.
Kolinji	*Tephrosia purpurea*, Pers.
Korra	See tenai.
Korukkai	*Pithecolobium dulce*, Benth.
Margosa	See neem.
Maruthu	*Terminalia arjuna*, W & A.
Nanal	*Ochlandra travancorica*, Gamb.
Napier grass	*Pennisetum purpureum*, Schum.
Neem	*Azadirachta indica.*
Neernochi	*Vitex trifolia*, L.f.
Odai	*Acacia latronum*, Willd.
Paddy	*Oryza sativa*, Linn.
Palmyra	*Borassus flabellifer*, Linn.
Pillipesara	*Phaseolus trilobus*, Ait.
Potato	*Solanum tuberosum*, Linn.
Ragi	*Eleusine coracana*, Gaertn.
Redgram	*Cajanus indicus*, Spr.
Rye grass	*Lolium perenne*, Linn.
Safflower	*Carthamus tinctorius*, Linn.
Screwpine	*Pandanus tectorius*, Sol.
Tamarind	*Tamarindus indica*, Linn.
Tenai	*Setaria italica*, Beauv.
Thillai	*Excoecaria agallocha*, L.
Timothy	*Phleum pratense.*
Tobacco	*Nicotiana tabacum*, Linn.
Tur	*Cajanus indicus*, Spr.
Usil	*Albizzia amara*, Boiv.
Virali	*Dodonea viscosa*, Linn.
Wheat	*Triticum* spp.

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